A PETROGRAPHIC STUDY OF
PRESSURE SOLUTION CLEAVAGE
IN
METAGREYWACKES OF THE GOLDENVILLE FORMATION,
MEGUMA GROUP, NOVA SCOTIA

A PETROGRAPHIC STUDY OF PRESSURE SOLUTION CLEAVAGE IN METAGREYWACKES OF THE GOLDENVILLE FORMATION, MEGUMA GROUP, NOVA SCOTIA

By

MARY JOANNE THOMPSON

A Thesis

Submitted to the Faculty of Science

in Partial Fulfilment of the Requirements

for the Degree

Bachelor of Science

McMaster University

April, 1984

HONOURS BACHELOR OF SCIENCE (1984) (Geology)

McMASTER UNIVERSITY
Hamilton, Ontario

TITLE: A Petrographic Study of Pressure Solution Cleavage in Metagreywackes of the Goldenville Formation, Meguma Group, Nova Scotia

AUTHOR: Mary Joanne Thompson

SUPERVISOR: Dr. P. M. Clifford

NUMBER OF PAGES: viii, 50

To My Mom and Dad

Abstract

Metagreywackes of the Goldenville Formation, Nova Scotia, possess a well developed spaced cleavage. Petrographic evidence suggests that the dominant mechanism producing this cleavage has been pressure solution, involving the dissolution of quartz from cleavage zones. A large amount of shortening occurs during cleavage development due to this volume loss of quartz. Based on a simple comparison of amounts of mica in cleavage and lithon zones shortenings of 50 - 60% have been found.

Cleavage zones are marked by distinct mineralogical variations, notably a high content of white mica, and a low quartz content. Trends for all components have been documented to characterize the cleavage and lithon zones.

Acknowledgments

Dr. P.M. Clifford, affectionately known as Doc Cliff, has helped me throughout my university years as well as supervising this thesis. For his friendship, helpfulness and for putting up with all my craziness, I offer my very sincere thanks.

Thank you also to Mrs. Helen Thompson for typing, Jack Whorwood for photography, Len Zwicker for thin sections and John Kelman for assistance with drafting.

A very special thank you goes to Gordon McRoberts for all his help and support. And finally thanks to my friends who have made my years at Mac very worthwhile.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

1.1 Introduction

Investigations of possible influences or controls on gold localization in Meguma Group rocks of Nova Scotia (Henderson, 1983; Fueten et al., 1983) suggest strongly that one process of importance is pressure solution. Various attempts have been made to characterize the effects of pressure solution in the Meguma Group rocks. The purpose of this present study is to investigate the nature of the cleavage developed in the Goldenville Formation of the Meguma Group.

1.2 Pressure Solution

The idea of pressure-induced solution as a means of re-arranging constituents of certain rocks is not new. Sorby (1863) implied such a process and more recently there have been several papers dealing with pressure solution effects. Durney (1976) gives an excellent brief summary of the historical evolution of terms and ideas for this field.

A recent definition (de Boer, 1977) refers to pressure solution as "an intergranular diffusive mass transfer process in the fluid phase in response to stress gradients around grains". The emphasis on "intergranular" and "fluid phase" stems from the fact that the only mechanism likely to be capable of transport of large quantities of material is one which a) uses the intergranular spaces as channelways, and b) involves abundant water. The basic process is that grain surfaces are subjected to external forces and are likely to undergo solution from those surfaces which sense the highest stresses. The material removed from such surfaces will be transported to new sites for redeposition. The distances of transport are not normally known with any certainty. Beard-like overgrowths or coarsely-crystalline fringes may develop locally; these are termed "pressure shadows" or "pressure fringes". It is also possible that the dissolved material may migrate completely away from the local system.

The removal of dissolved material is likely to have noticeable mesoscopic effects. In silicic clastic rocks, stylolites and solution seams have been recorded, but a much more common response, especially in rocks metamorphosed to low metamorphic grade, is the production of a spaced cleavage (Beach, 1979; Harris et al., 1976; Williams, 1972). The sedimentary rocks which typically show the most evidence of having undergone deformation by pressure solution are immature sandstones and siltstones. These possess an obvious spaced cleavage, clearly defined by zones of high concentrations of phyllosilicates and spaced at fairly regular intervals. The metagreywackes of the Goldenville Formation of the Meguma Group have just such a cleavage.

The study reported here investigates the nature of this spaced cleavage. It concentrates on documenting the mineralogical variation in the rock which corresponds to cleavage development. Based upon such data, calculations have been made of the shortening represented by the cleavage. This is translated into an estimate of loss of silica from the system.

CHAPTER 2

2.1 General Geology

The greater part of mainland Nova Scotia is underlain by rocks of the Meguma Group which are intruded by granitic rocks mainly of Devonian age (Figure 2-1).

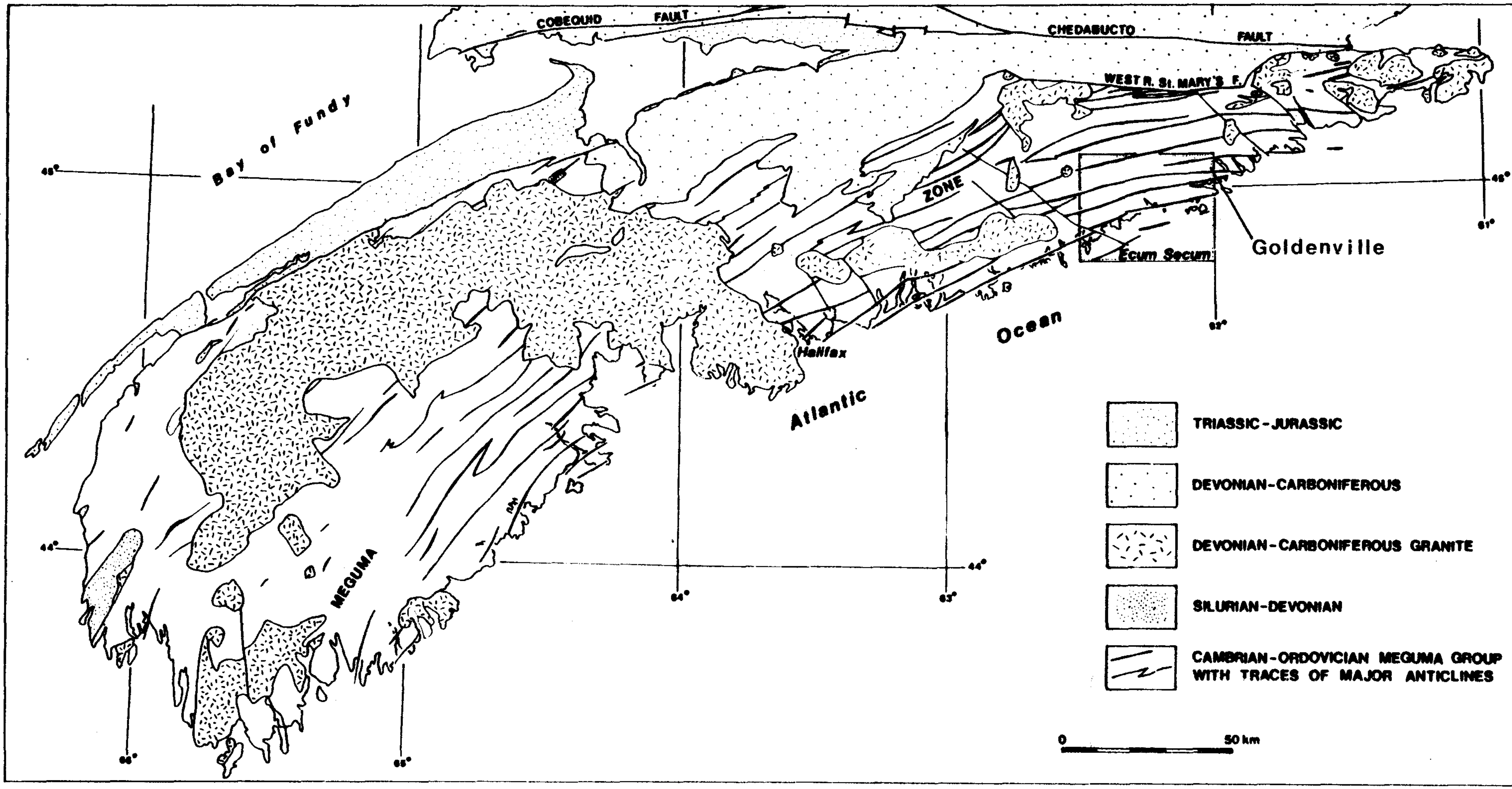
The Meguma Group is divided into two formations. The Goldenville Formation is the lower of the two and it consists of quartz-rich greywackes and interbedded argillite, with minor conglomerates, all metamorphosed to greenschist facies or higher. The argillite interbeds individually become thicker and collectively more abundant towards the top of the formation.

A wide range of sedimentary structures can be observed including parallel layering, graded bedding, cross-bedding, scour and fill, slumps, ripple marks, sand volcanoes and ball and pillow structures (Schenk, 1970). Some beds show sequences of some of these structures which have been interpreted as Bouma sequences. These are taken to imply that the Goldenville greywackes were deposited by turbidity currents (Schenk, 1970).

The Halifax Formation overlies the Goldenville Formation. It consists of thinly laminated shale with small amounts of interbedded siltstone (Schenk, 1970). Primary structures are present but are less common than in

Figure 2-1 Location Map

Goldenville, Nova Scotia



COBEQUID
FAULT
CHEDABUCTO
FAULT
WEST R. St. MARY'S F.
Bay of Fundy
ZONE
MEGUMA
Goldenville
Ecum Secum
Halifax
Atlantic
Ocean
45°
44°
66°
65°
64°
63°
62°
61°
TRIASSIC - JURASSIC
DEVONIAN - CARBONIFEROUS
DEVONIAN - CARBONIFEROUS GRANITE
SILURIAN - DEVONIAN
CAMBRIAN - ORDOVICIAN MEGUMA GROUP WITH TRACES OF MAJOR ANTICLINES
0
50 km

the Goldenville Formation. The contact between the two formations is conformable; it ranges from gradational to sharp (Graves, 1976).

According to Schenk (1971), the Meguma Group is Cambro-Ordovician in age. Detrital muscovite from the Goldenville Formation has been dated as Lower Ordovician (Poole, 1971).

Regional metamorphism up to greenschist grade generally, and up to mid-amphibolite grade in some places occurred during the Acadian Orogeny (Fyson, 1967; Taylor and Schiller, 1966). At the same time, the rocks were deformed into a set of folds which in the Ecum-Secum area (Figure 2-1) have shallow but doubly plunging axes. Axial surfaces are generally upright and strike east-west. These folds are arranged en-echelon (Henderson, 1983). A spaced cleavage developed as a part of this deformational phase and fans about the axial surface. This cleavage is inferred to have been initiated while the beds were still horizontal or nearly so. Cleavage zones are parallel to water escape structures, which may be taken as originally bedding normal and just post-depositional (Henderson, 1983; Fueten et al., 1983). The cleavage fanning is probably the result of adjustments (flexural slip or possibly homogeneous flattening) which took place as folds evolved and limb dips increased.

2.2 Petrography

The samples used in this study came from an anticline in the Goldenville Formation, at the settlement of Goldenville (Figure 2-1). Recent exploration work has yielded numerous cores which provided clean, unweathered samples. These same samples have been assessed for strain (Pryer, 1984) and have also been analysed chemically (Fueten, in preparation). As a consequence, results from different methods of analysis can be compared.

2.2.1 Methodology

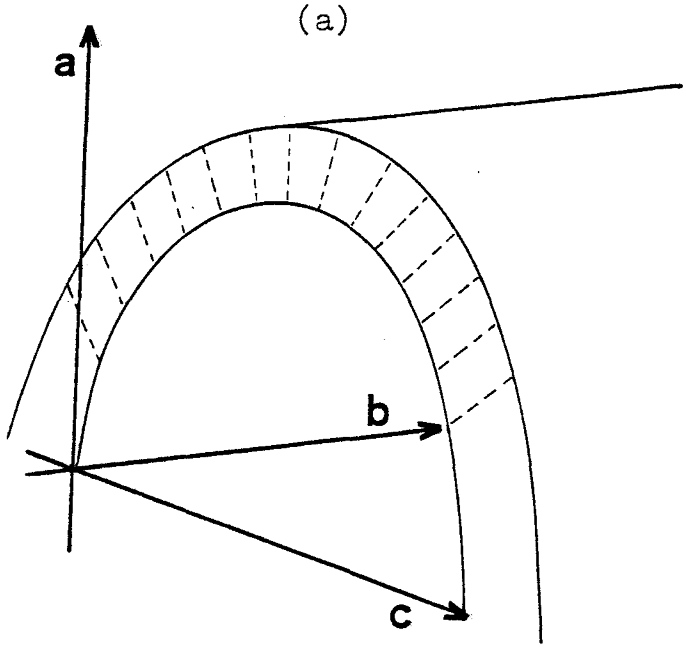
For detailed study, four samples were sectioned parallel to ac and bc planes (Figure 2-2a). Thus variations can be viewed three-dimensionally. Each thin section was point counted, using a 0.3 mm increment on a mechanical stage. A series of 9 mm lines (30 points) were counted parallel to the macroscopic cleavage planes (Figure 2-2b). The number of lines and thus the number of points counted per slide varied, depending upon cleavage development in the particular section. In most cases, counting was continued until two cleavage planes had been crossed.

At the same time, orientations of basal cleavage planes in micas were recorded. The mean cleavage was taken as a reference (zero) line.

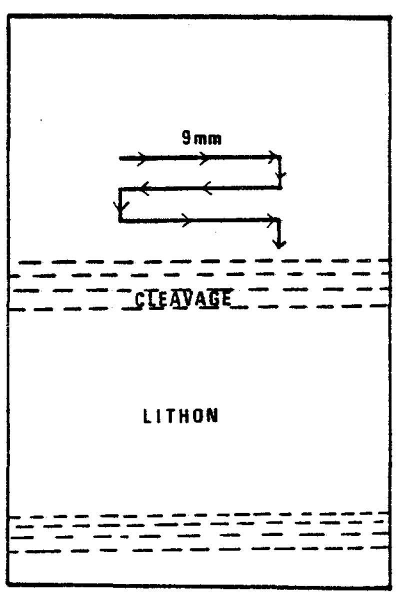
Figure 2-2a Diagramatic representation of an anticline showing section orientations. Cleavage is shown forming a convergent fan.

Figure 2-2b Diagramatic representation of counting procedure.

(a)



(b)



All data have been graphed for ease of discussion. Statistical means for the orientation histograms were calculated by vector analysis methods (Watson, 1966).

2.2.2 Mineralogy

The mineralogy in all samples is similar and analysis of the point count data indicates that the samples are approximately 68% quartz. Table 2-1 gives the results of modal analysis of the slides.

Two distinct size populations of quartz grains occur. About 35% of the quartz is clearly detrital, the grains being relatively large (0.2 mm to 0.5 mm average, and some grains as large as 1.0 mm), anhedral and monocrystalline (Figure 2-3). Undulatory extinction is observed in these grains, indicative of mild strain. Many of the grains have quartz or mica beards (pressure shadows) (Figure 2-4). In the cleavage zones, detrital quartz grains have clearly been trimmed by pressure solution, resulting in rectangular or elongate shapes (Figure 2-5). This reduces the average grain area of detrital quartz in the cleavage relative to the lithon zones.

The other size population consists of fine grained, possibly recrystallized quartz. This type occurs predominantly in the lithon and accounts for

TABLE 2-1

Modal Analyses from Point Count Data

Sample	QUARTZ	WHITE MICA	DARK MICA	OPAQUES	CARBONATE	FELDSPAR
G19-354 AC	68.3	23.0	2.7	1.0	3.6	1.3
G19-354 BC	68.0	20.4	6.2	0.8	3.5	1.0
G20-753 AC	67.0	23.5	4.9	1.6	1.4	1.4
G20-753 BC	73.2	17.7	4.5	1.3	2.1	1.1
G26-353 AC	68.1	24.9	2.9	1.1	1.7	1.2
G26-353 BC	68.7	23.6	3.3	1.3	2.5	0.6
G26-415 AC	68.6	26.0	1.4	2.0	1.7	0.3
G26-415 BC	58.8	34.0	2.2	1.9	2.2	0.9
OVERALL AVERAGES	68%	24%	4%	1%	2%	1%

Figure 2-3 Slide G19-354

Cleavage zones are lighter bands of high mica concentration. Note anhedral detrital quartz grains are larger in lithon zones and often "trimmed" in cleavage zones to rectangular shapes. White grains are opaque minerals. Photograph is 2.5 cm X 4.0 cm.

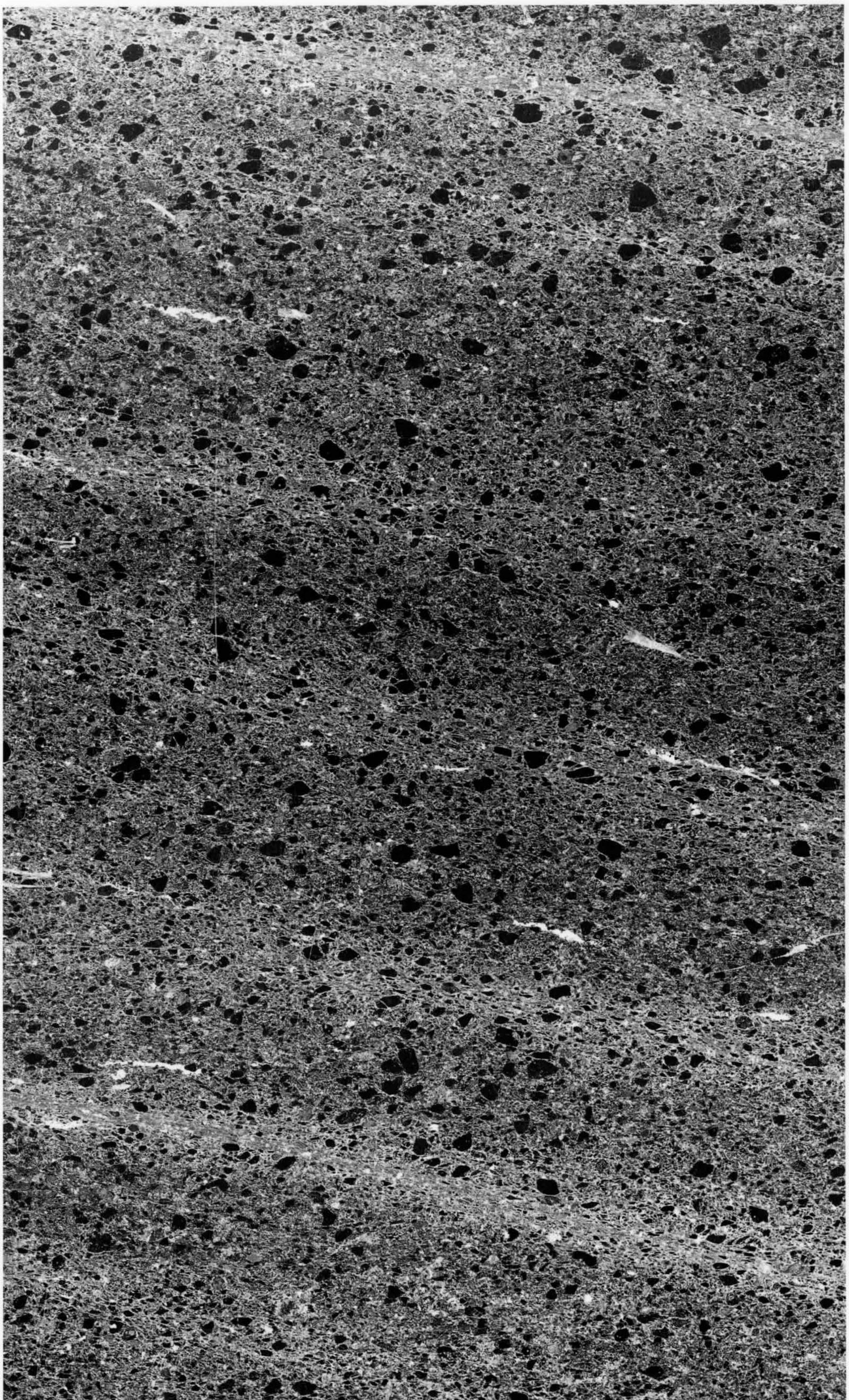
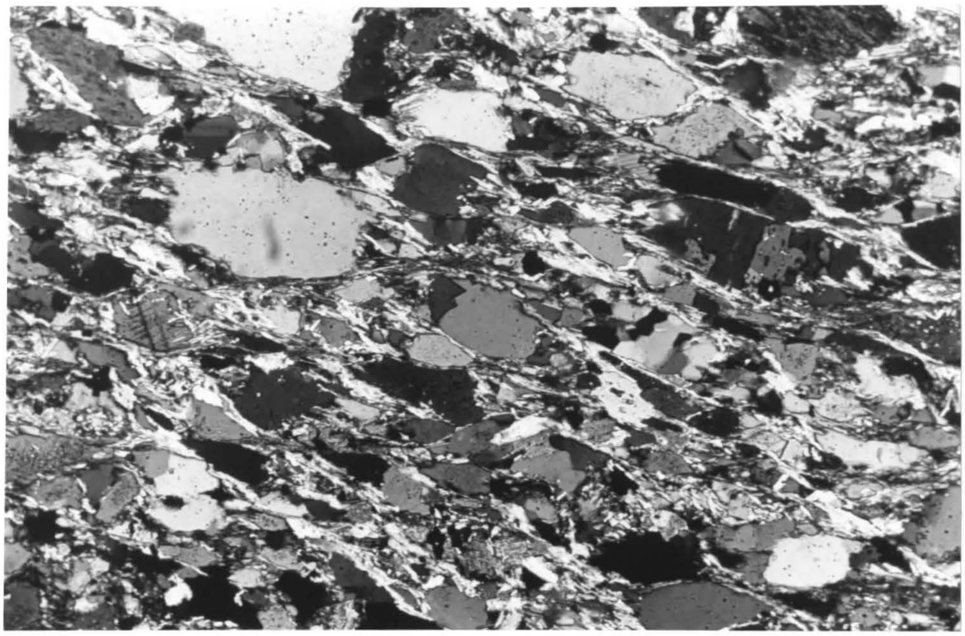
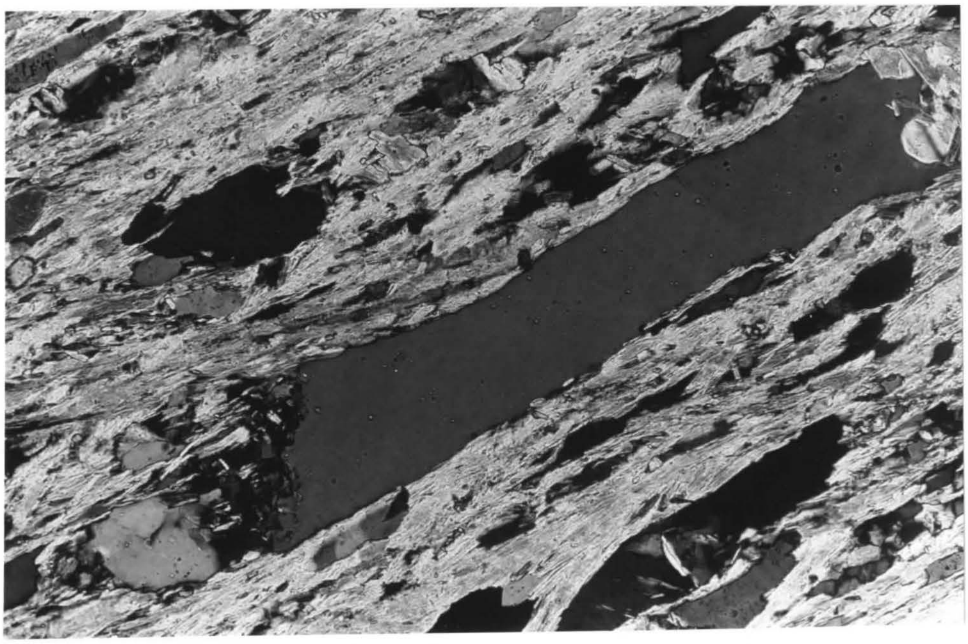


Figure 2-4 Note mica "beards" on detrital quartz grains. The photograph width is 3.0 mm.

Figure 2-5 Rectangular quartz grain due to pressure solution "trimming". Note mica beards at the ends of the grain. The length of the grain is 0.5 mm.





approximately 65% of the total quartz content. On average, grainsize is less than 0.1 mm; grains are subhedral and often polygonal in shape with straight grain boundaries. Strained extinction is not predominant.

Large polycrystalline aggregates are observed which may possibly be recrystallized detrital quartzite fragments, however, they are not common. The inter-crystalline boundaries vary from irregularly sutured to polygonal and the outer grain boundaries are generally smooth.

Phyllosilicates make up approximately 28% of the rock composition; of these, the majority are white micas (24%). Well over half this amount occurs in and thus defines the cleavage zones. About 4% is "dark mica" which includes the biotite and chlorite content of the samples.

The white mica crystals are generally well developed, elongate flakes which vary in size and orientation. The length (measured parallel to basal cleavage) ranges up to 0.5 mm, with the average grainsize in the cleavage zones generally larger than in the lithons. The crystals occur surrounding quartz and feldspar grains, often in clusters as pressure shadow beards.

Biotite generally occurs as small, anhedral crystals and is often associated with opaque minerals in the cleavage zones. Occasional large subhedral grains (0.4 mm) are developed in cleavage zones as well. Chlorite occurs as very fine, anhedral to subhedral crystals randomly dispersed throughout the samples.

Minor amounts of feldspar, carbonate, pyroxene and opaque minerals make up the last 5% of the total sample composition. The feldspar has been determined to be albite based on the Michel-Levy method. It occurs as anhedral grains of variable sizes, up to approximately 0.4 mm. Anhedral carbonate occurs filling intergranular spaces. Twinning is apparent in several grains and the twin lamellae are slightly deformed. Well rounded detrital pyroxene grains are present but are rare and small (less than 0.1 mm).

Two types of opaque minerals have been distinguished. A low percentage consists of tiny (less than 0.1 mm), euhedral, sharp-edged crystals which contrast with the more common anhedral, variable size, elongate grains (Figure 2-3). These elongate opaques are slightly more abundant in the cleavage zones.

2.3 Mineral Distributions

2.3.1 Micas

The cleavage zones are obviously zones of enrichment in or concentrations of phyllosilicates (Figure 2-3). To quantify this, the percentage of phyllosilicates and the proportions of each species was recorded for each line counted.

Graphs of mica variation have been prepared for each sample (Figures 2-6a-f). These graphs demonstrate that there are distinct differences in mica content corresponding to cleavage and lithon zones.

Lithons consistently have 20% or less mica, and cleavage zones correspond to counts of 30% mica or more. The precise values for each of these two domains vary from section to section, depending upon the degree of cleavage development. But accepting a level of at least 30% phyllosilicate as denoting a cleavage zone works well for all samples.

Generally the graphs emphasize both the relative abundance of micas in cleavage zones as compared to lithons and the increasing contrasts in the mica abundances in the two domains as cleavage zones were judged mesoscopically to be "better developed". Sample G20-753 has a poorly developed cleavage, diffuse and rather inconspicuous;

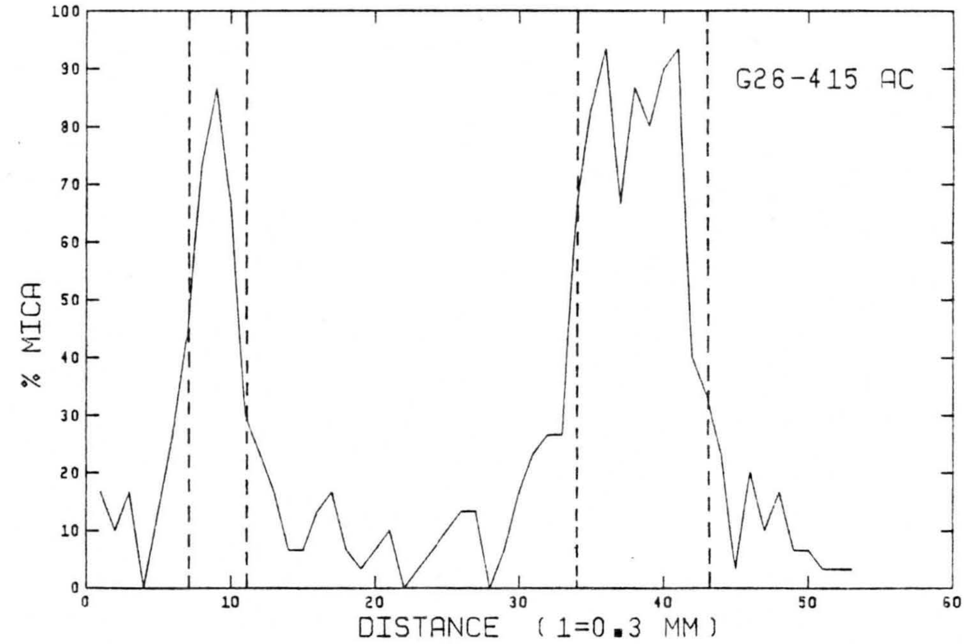
Figures 2-6a to 6d

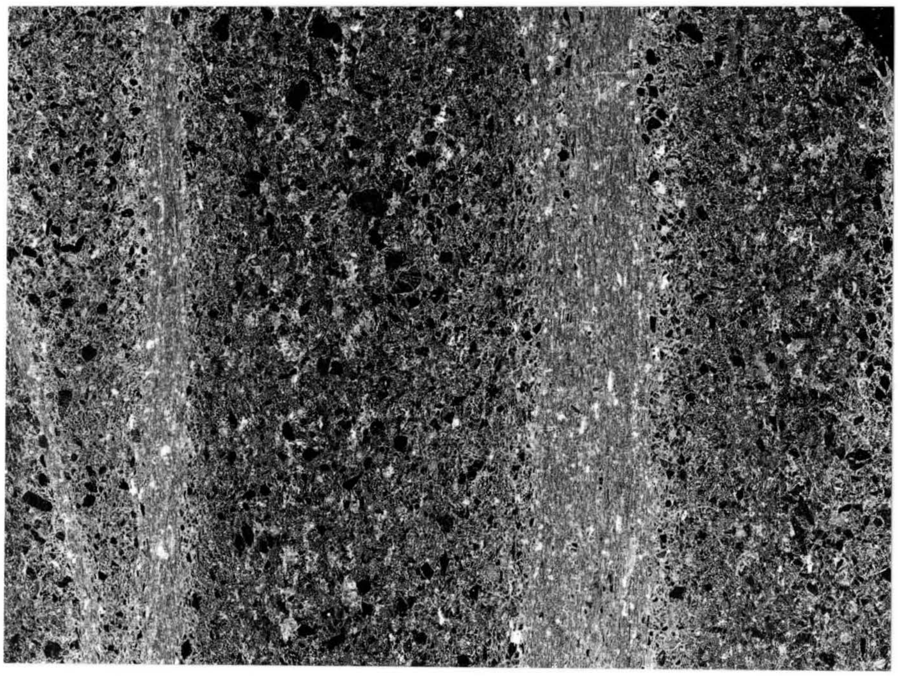
Variations in mica content across samples. Vertical dashed lines represent cleavage zones.

Comparison of photographs and graphs demonstrates cleavage zones to be areas of mica enrichment (average $>$30% mica).

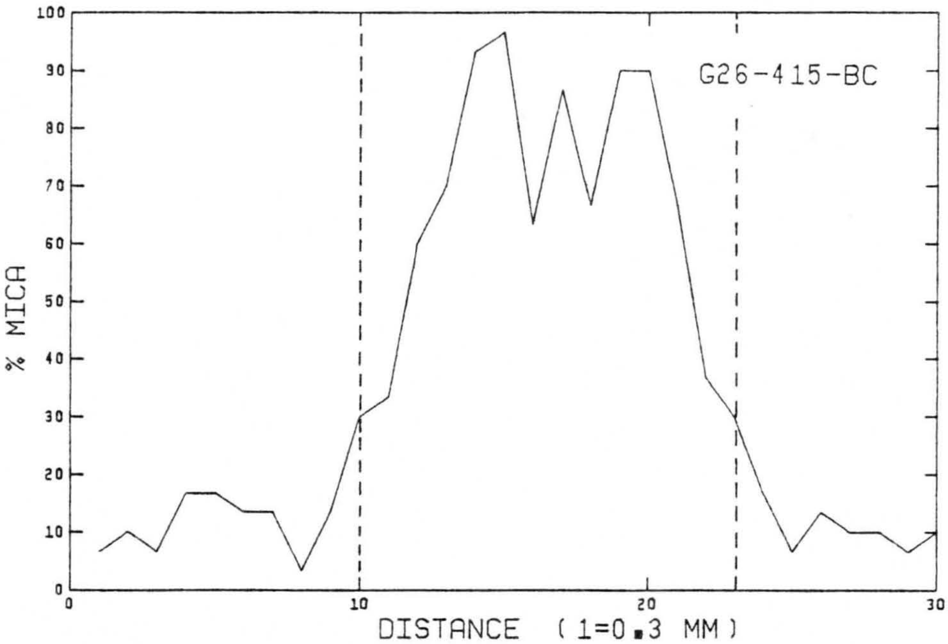
a)	G26-415 AC	Note well developed cleavage zones, wide and sharply defined.
b)	G26-415 BC	
c)	G19-354 AC	Cleavage zones defined by average mica concentration $>$ 30%.
d)	G19-354 BC	

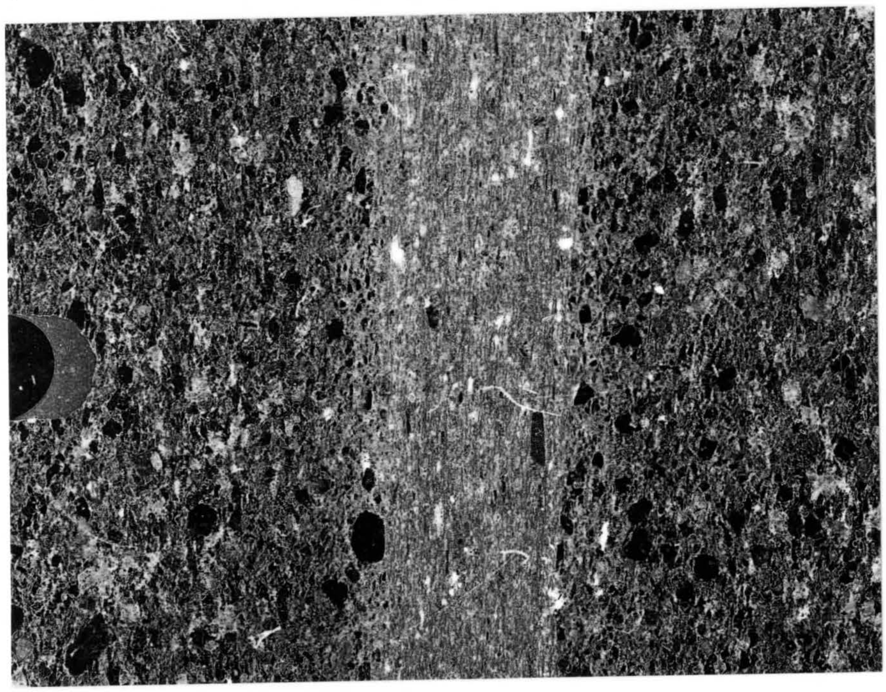
(a)


G26-415 AC
% MICA
DISTANCE (1=0.3 MM)
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50
60

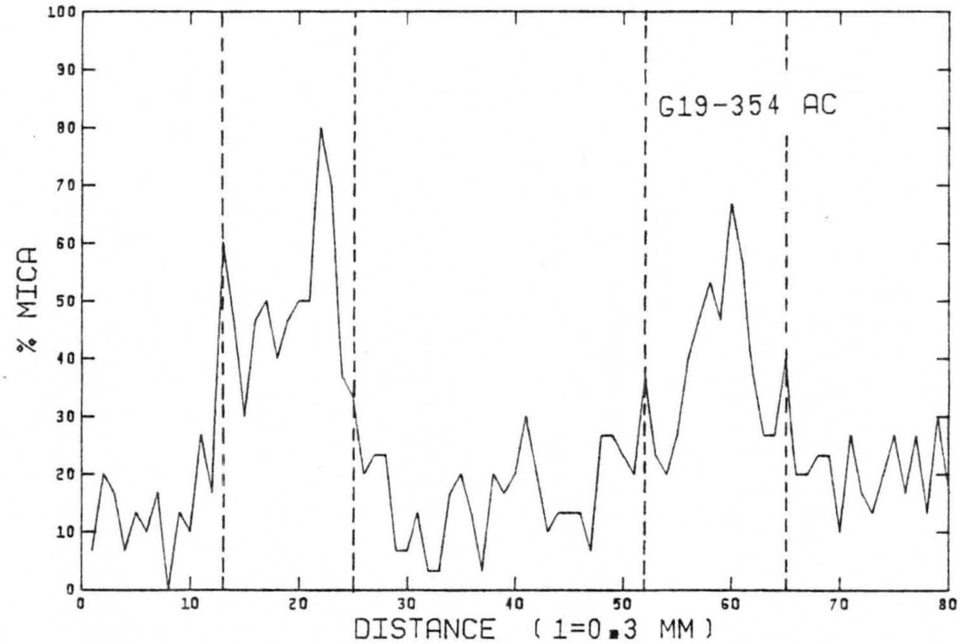


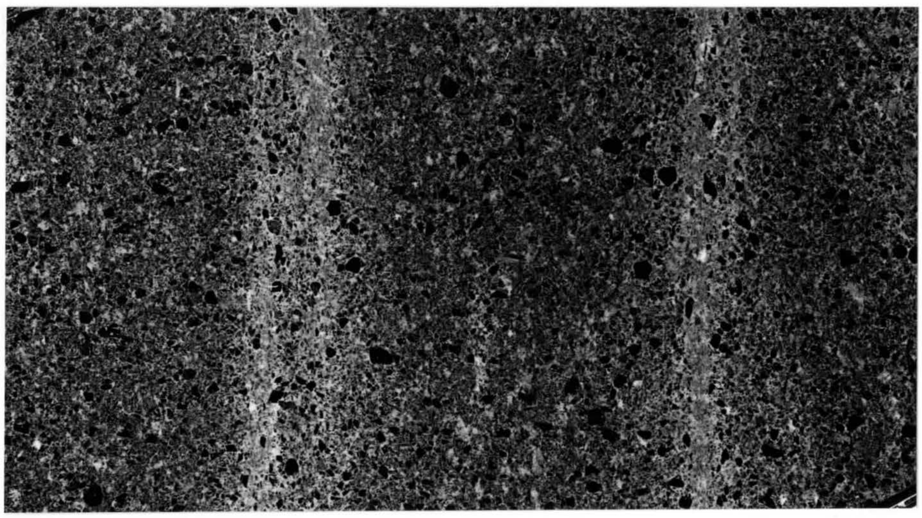
(b)



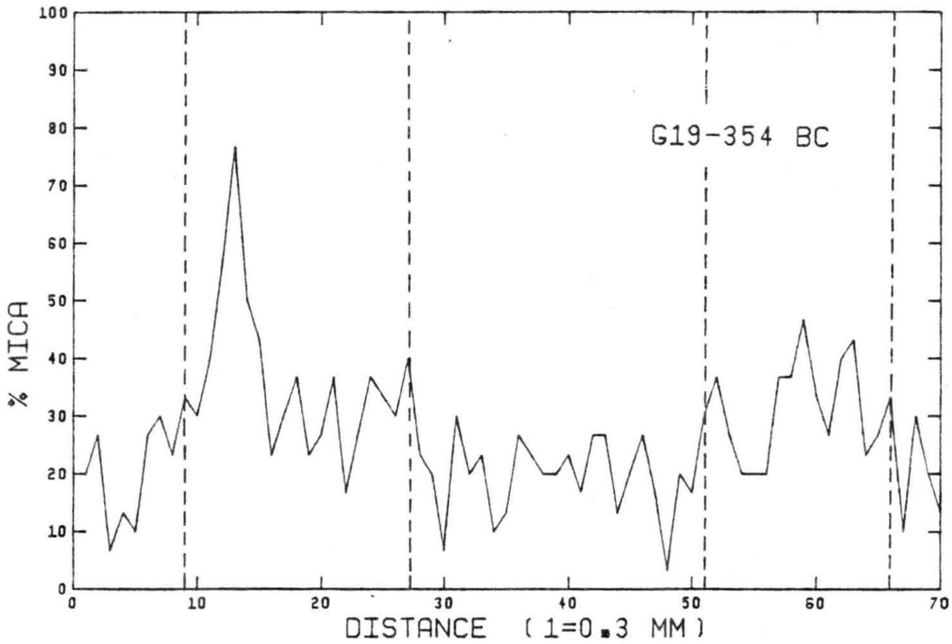


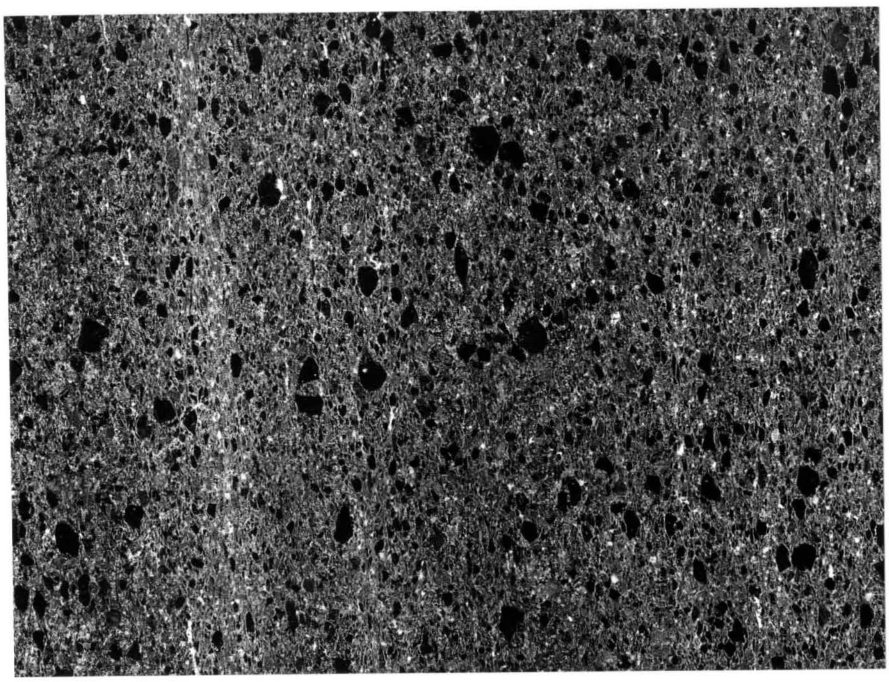
(c)


G19-354 AC
% MICA
DISTANCE (1=0.3 MM)
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80



(d)



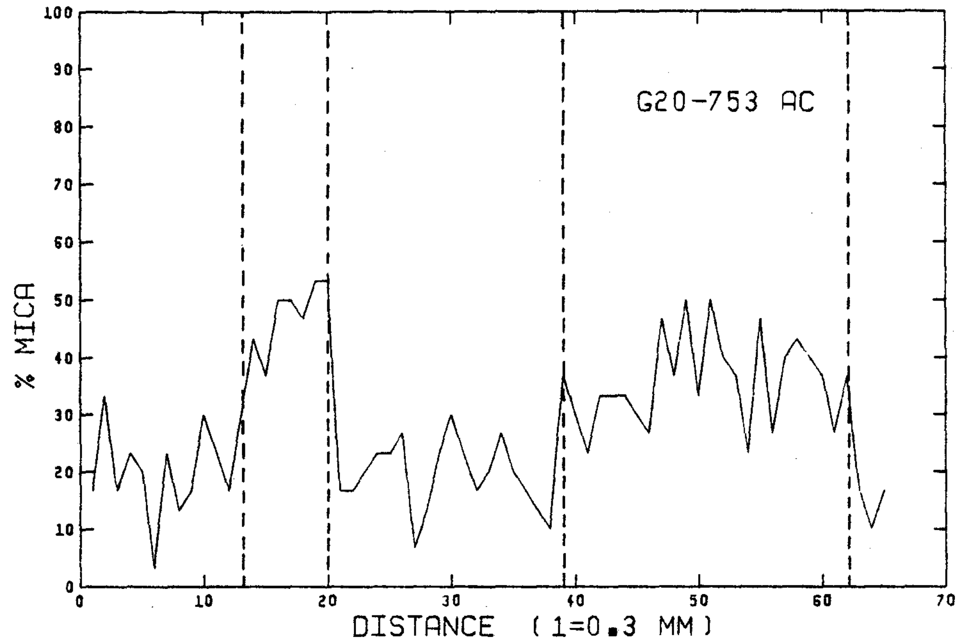


Figures 2-6e and 2-6f

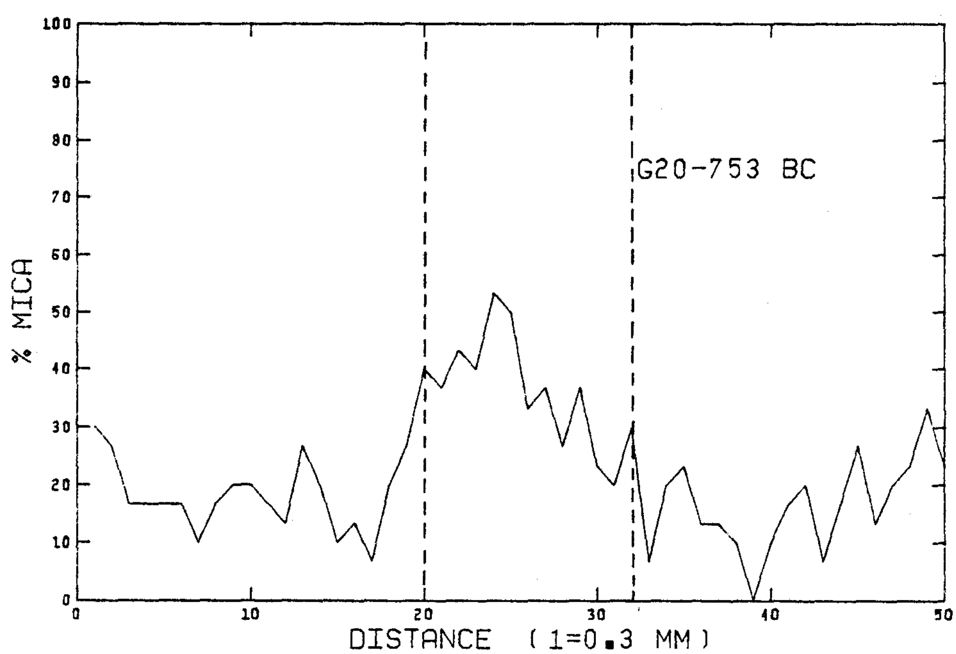
Variations in mica content across samples. Vertical dashed lines represent cleavage zones.

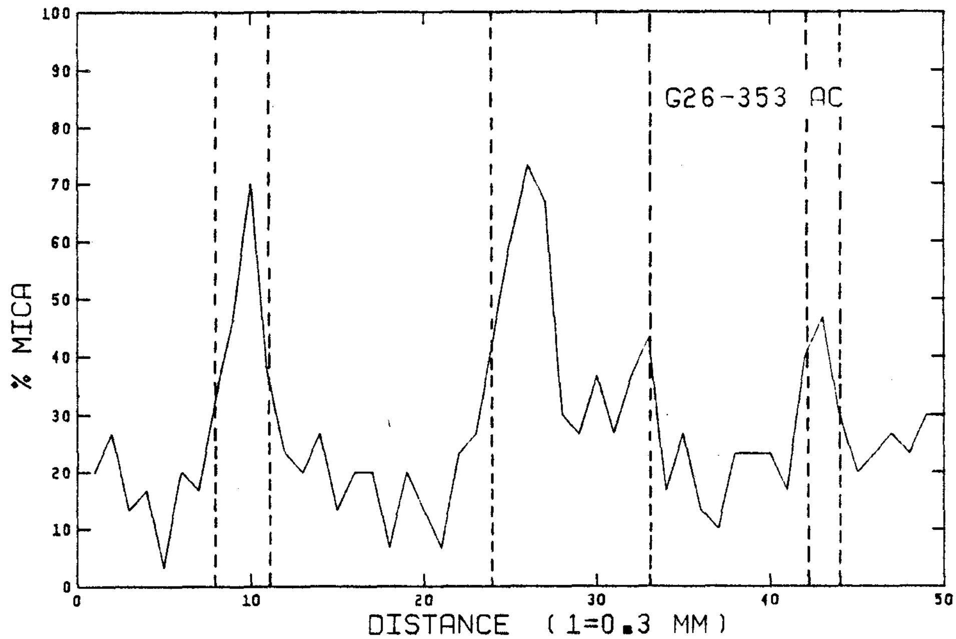
e) G20-753 AC
G20-753 BC

f) G26-353 AC
G26-353 BC

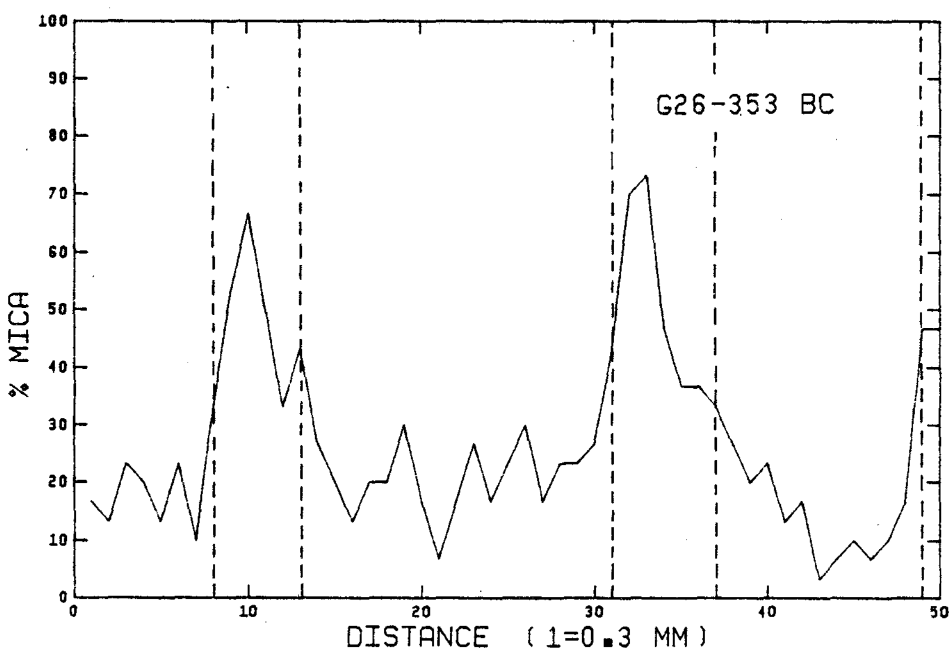

G20-753 AC
% MICA
DISTANCE (1=0.3 MM)
0
10
20
30
40
50
60
70
80
90
100

(e)


G20-753 BC
% MICA
DISTANCE (1=0.3 MM)
0
10
20
30
40
50
60
70
80
90
100


G26-353 AC
% MICA
DISTANCE (1=0.3 MM)
0
10
20
30
40
50
60
70
80
90
100

(f)


G26-353 BC
% MICA
DISTANCE (1=0.3 MM)
0
10
20
30
40
50
60
70
80
90
100

average mica abundance in the lithon is slightly less than 20% and in cleavage zones only 35-45%. In contrast, sample G26-415 (Figure 2-6a) has a well defined cleavage zone. There are about 10% micas in the lithons and about 70% in the cleavage zone.

Average values of mica abundance are given in Table 2-2. Differences between ac and bc sections are due to the fact that cleavage zones are not necessarily the same for both sections.

In addition to the contrasting mica abundance in cleavage zones, it is clear that the increase of mica is due to an increase in the white mica content only. Figures 2-7a to 2-7d show the variation in the two micas, where dark micas include chlorite. Generally, dark mica is uniformly low in abundance whether in lithon or cleavage zones, whereas the white mica increases significantly in the cleavage zones, accounting for the variations observed in the total mica abundances.

2.3.2 Quartz

Figures 2-8a to 2-8d show substantial variations in abundance of quartz in lithons and cleavage zones, qualitatively the inverse of variations in mica abundances. Again, poorly developed cleavage zones show a less well defined contrast between lithon and cleavage zone as compared to well developed cleavage zones (compare G20-753 and G26-415).

TABLE 2-2

Average values of Mica Abundance
in Cleavage and Lithon zones for each sample.

SAMPLE	CLEAVAGE	LITHON
G19-354 AC	44%	17%
G19-354 BC	34%	19%
G20-753 AC	38%	19%
G20-753 BC	36%	17%
G26-353 AC	44%	20%
G26-353 BC	48%	18%
G26-415 AC	69%	11%
G26-415 BC	65%	11%

Figures 2-7a to 7d

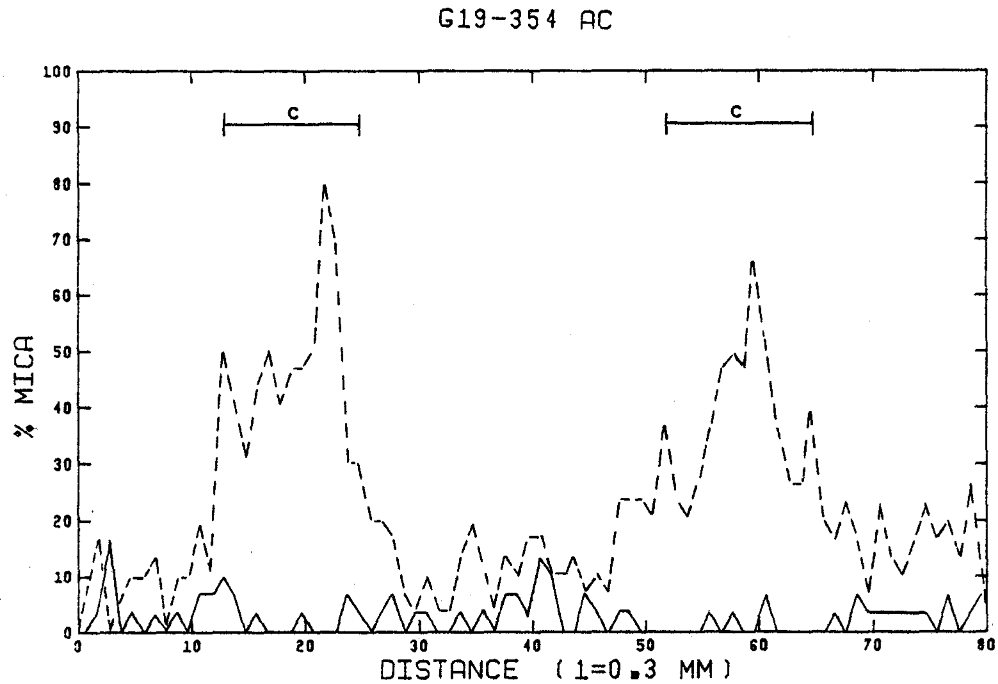
Variations in white and dark mica across samples.

For all graphs:

- dashed line represents white mica
- solid line represents dark mica
- cleavage zones are marked by distance bars

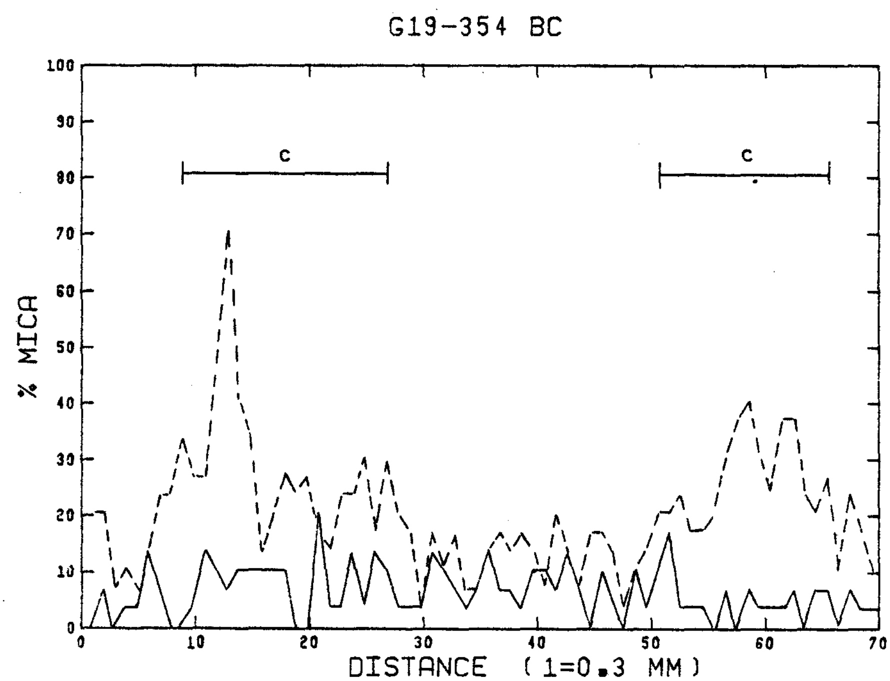
Note:

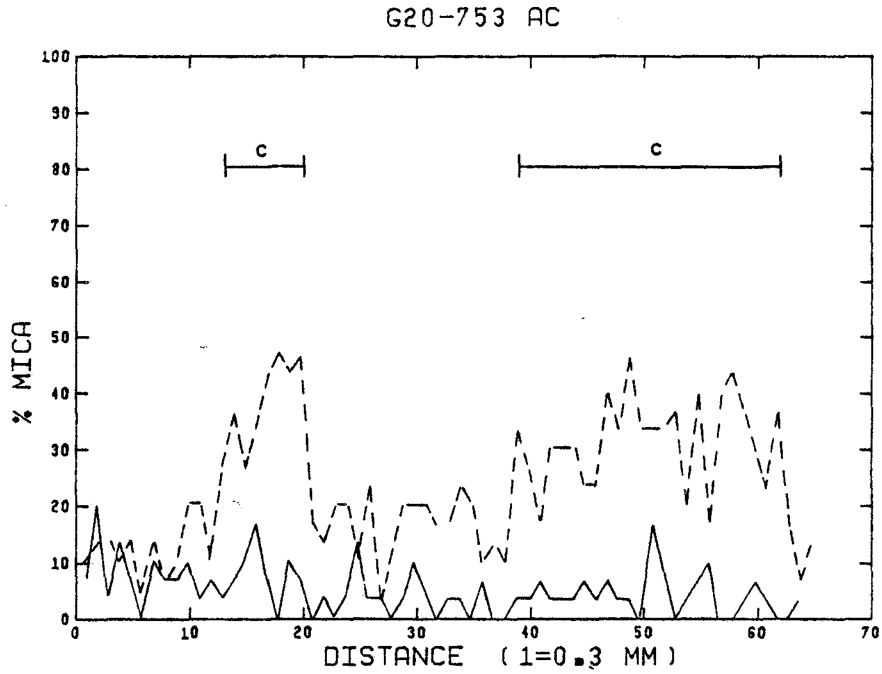
- substantial increases occur only in white mica content in cleavage zones
- no significant trends are apparent in dark mica content


G19-354 AC
c
c
% MICA
DISTANCE (1=0.3 MM)

c = Cleavage

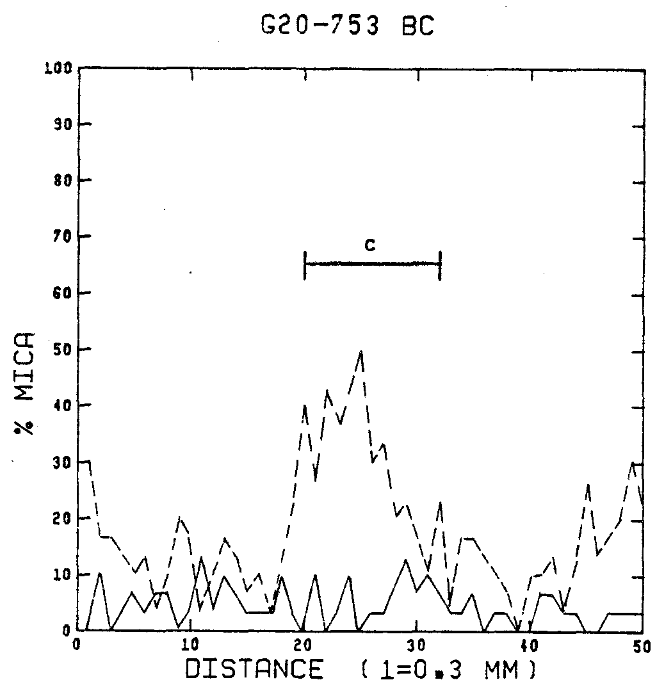
(a)

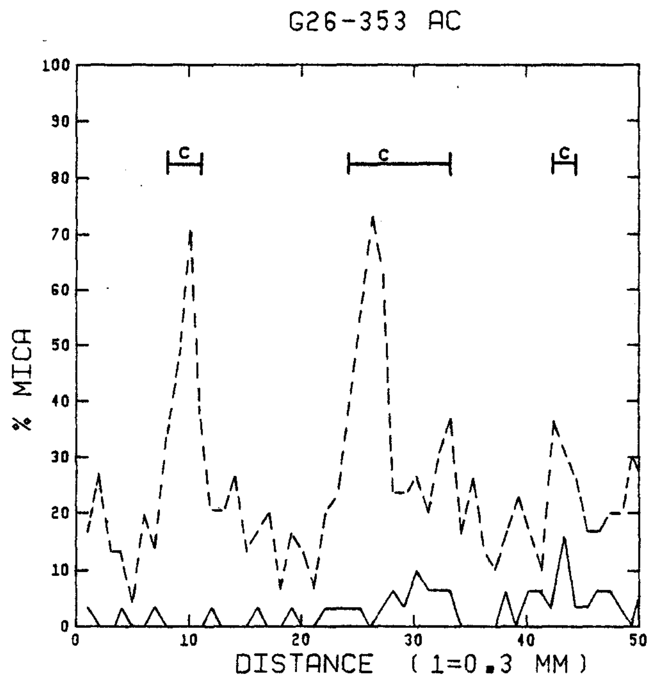

G19-354 BC
c
c
% MICA
DISTANCE (1=0.3 MM)


G20-753 AC
% MICA
DISTANCE (1=0.3 MM)
c
c

c=Cleavage

(b)

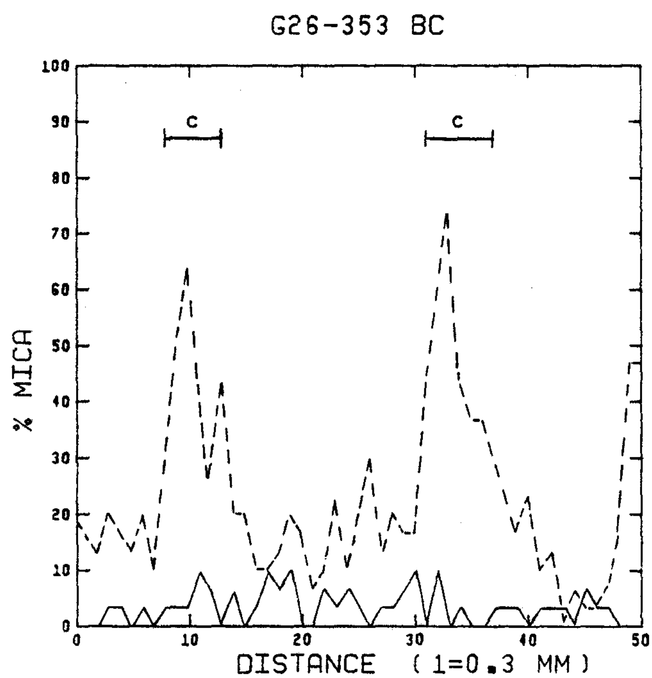

G20-753 BC
% MICA
DISTANCE (1=0.3 MM)
c



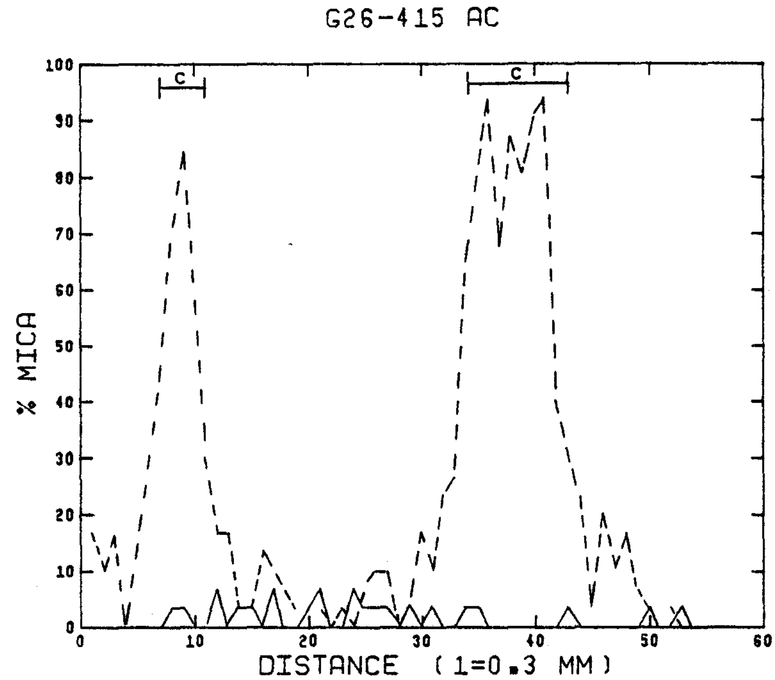
G26-353 AC
% MICA
DISTANCE (1=0.3 MM)
c
c
c

c = Cleavage

(c)

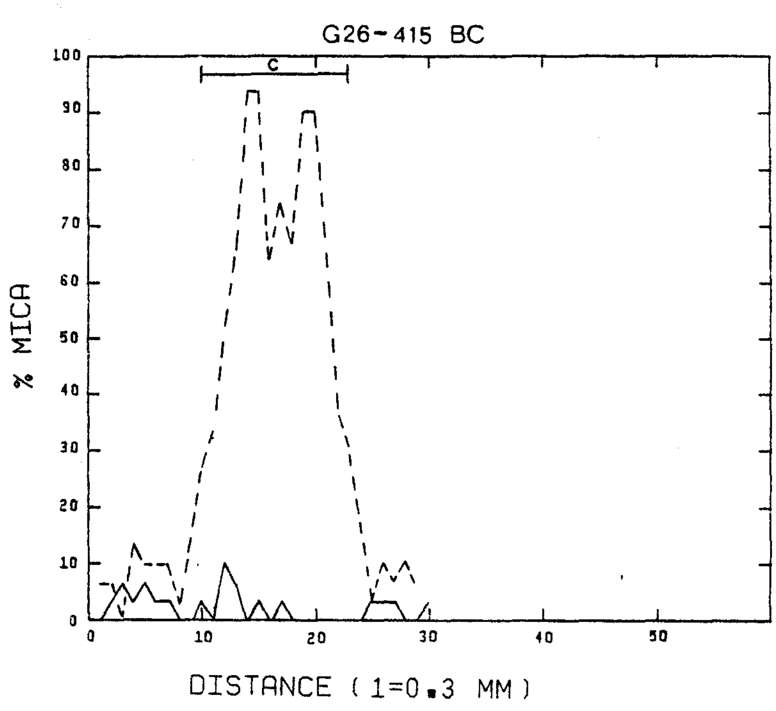


G26-353 BC
% MICA
DISTANCE (1=0.3 MM)
c
c


G26-415 AC
c
c
% MICA
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50
60
DISTANCE (1=0.3 MM)

C=Cleavage

(d)


G26-415 BC
c
% MICA
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50
DISTANCE (1=0.3 MM)

Figures 2-8a to 8d

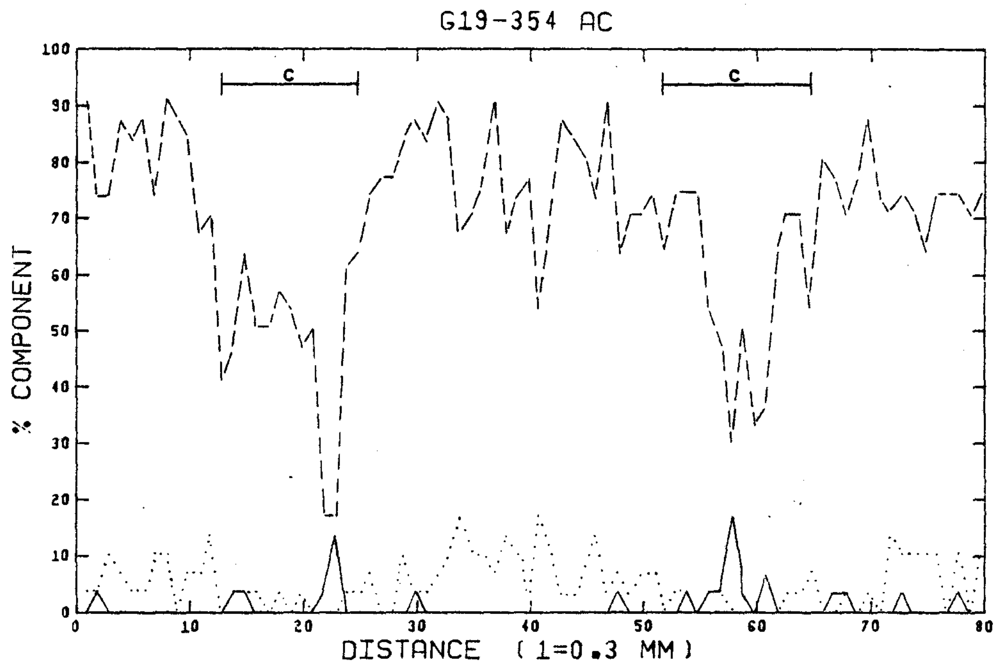
Variations in quartz, opaques, feldspar and carbonates across samples.

For all graphs:

- dashed line represents quartz
- solid line represents opaques
- dotted line represents feldspar and carbonate
- cleavage zones are marked by distance bars

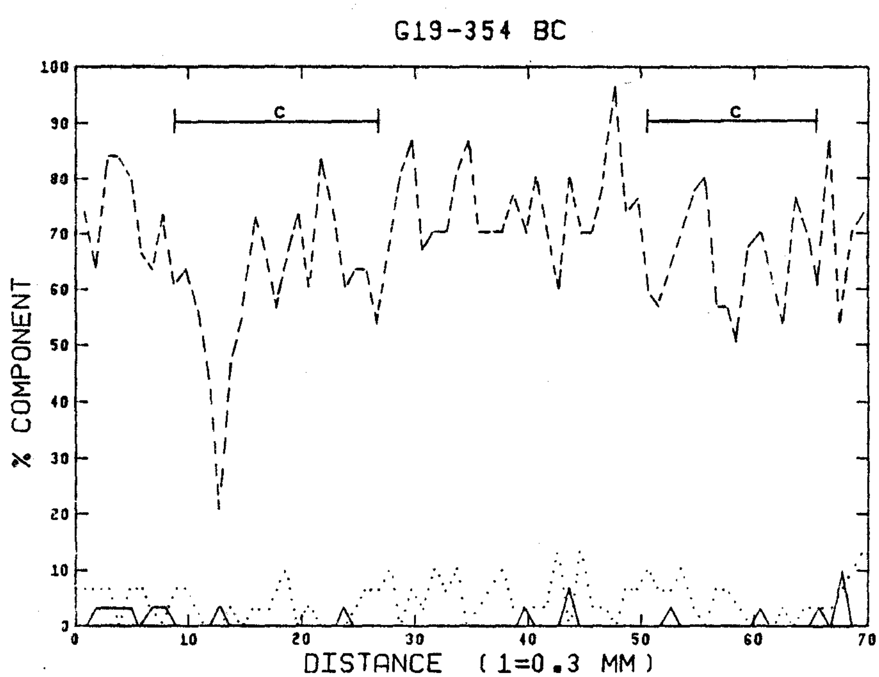
Note:

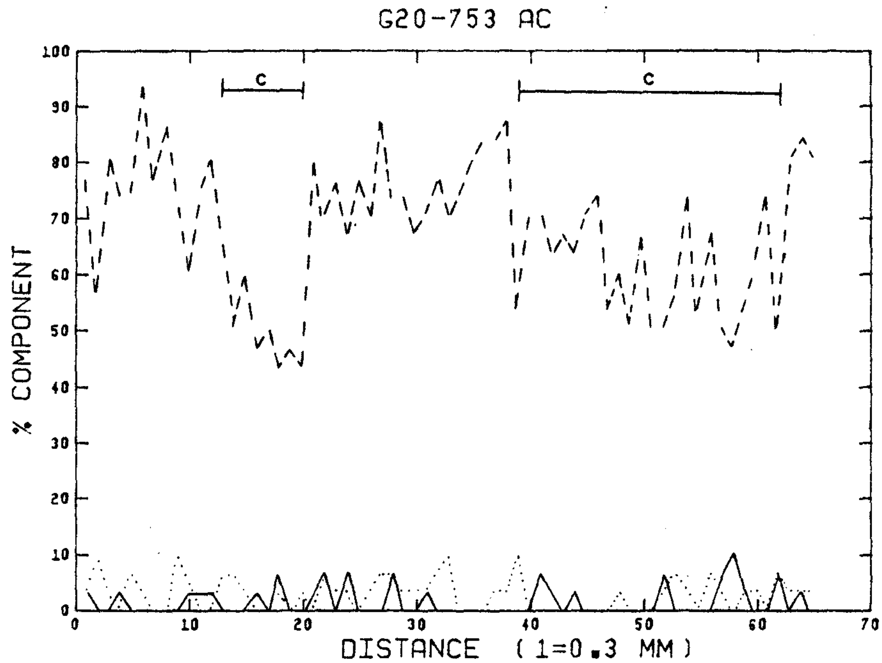
- decreases in quartz content in cleavage zones
- no significant trends are apparent for other components


G19-354 AC
c
c
% COMPONENT
DISTANCE (1=0.3 MM)

c= Cleavage

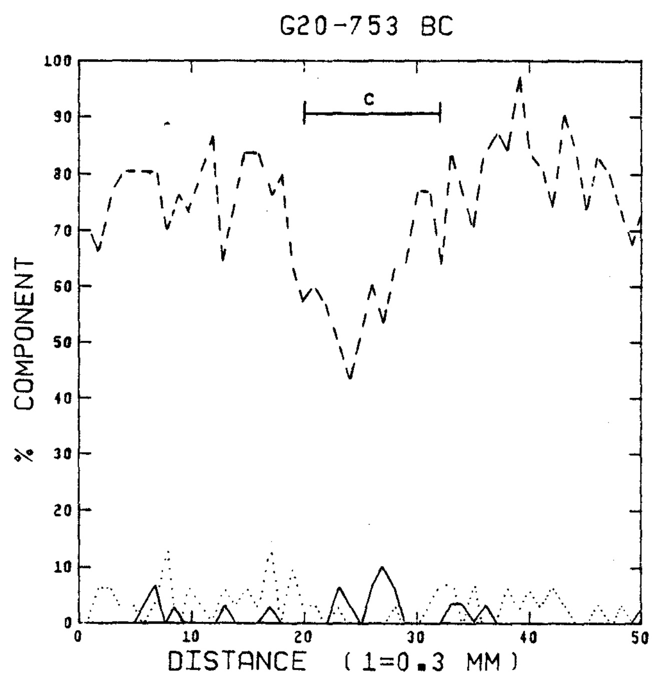
(a)

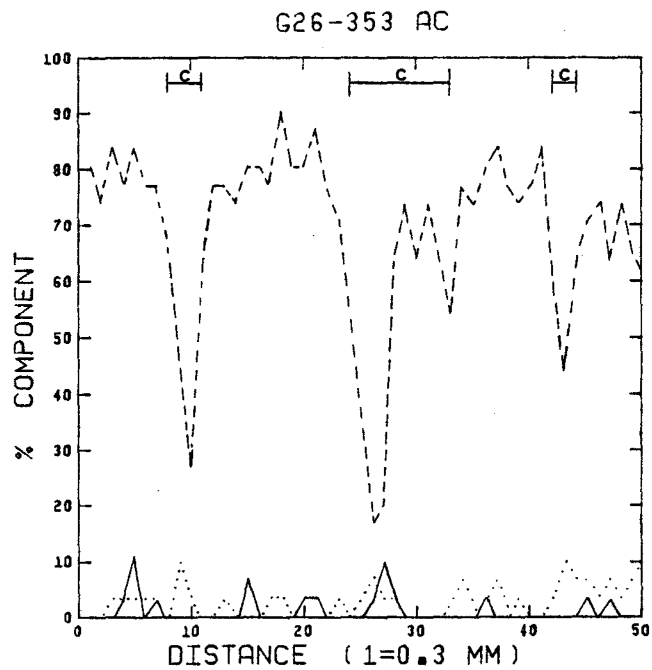

G19-354 BC
c
c
% COMPONENT
DISTANCE (1=0.3 MM)


G20-753 AC
C
C
% COMPONENT
DISTANCE (1=0.3 MM)
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50
60
70

C = Cleavage

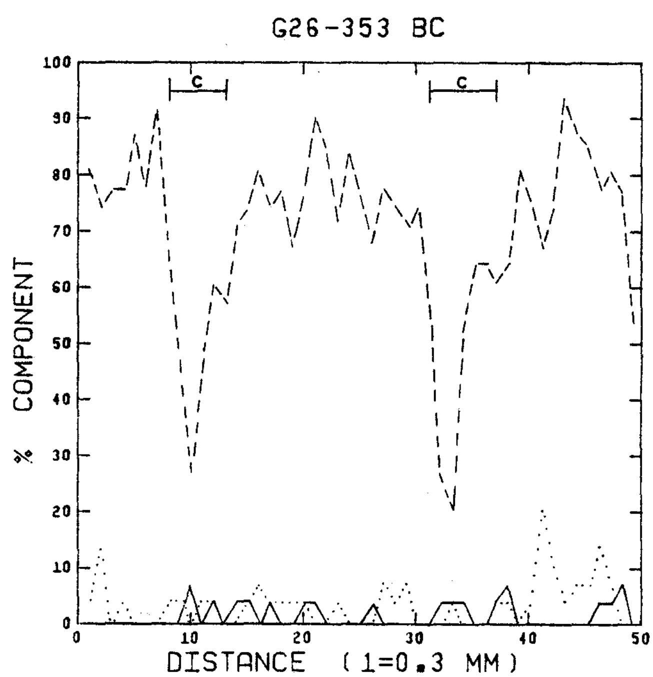
(b)

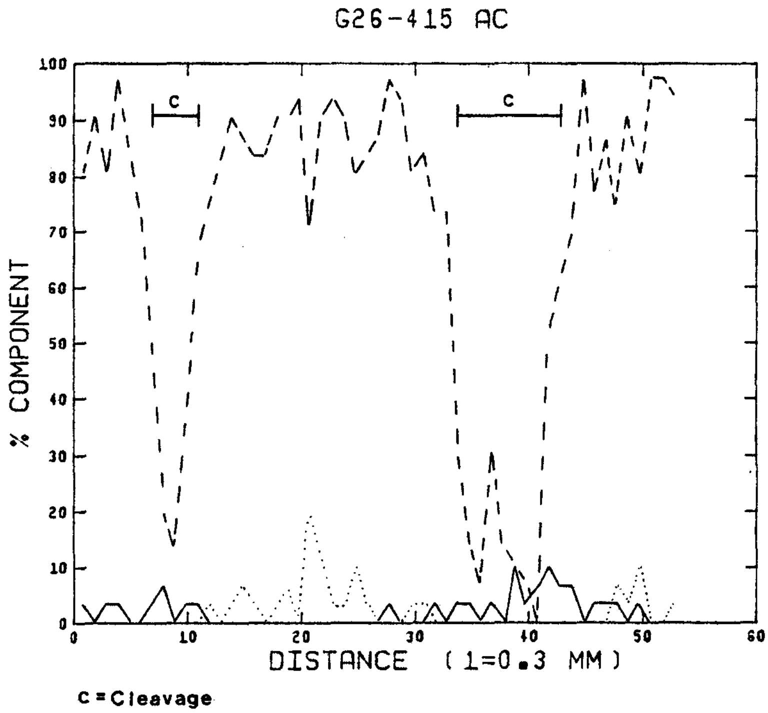

G20-753 BC
C
% COMPONENT
DISTANCE (1=0.3 MM)
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50


G26-353 AC
c
c
c
% COMPONENT
DISTANCE (1=0.3 MM)
0
10
20
30
40
50
60
70
80
90
100

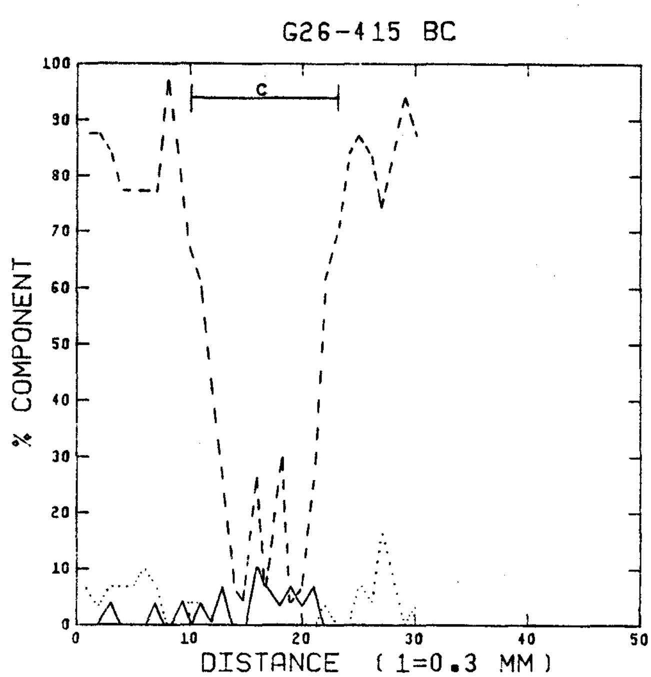
c = Cleavage

(c)


G26-353 BC
c
c
% COMPONENT
DISTANCE (1=0.3 MM)
0
10
20
30
40
50
60
70
80
90
100


G26-415 AC
% COMPONENT
DISTANCE (1=0.3 MM)
C
C
c = Cleavage

(d)


G26-415 BC
% COMPONENT
DISTANCE (1=0.3 MM)
C

2.3.3 Other Components

As noted earlier, these comprise about 5% of the total rock and thus the variations are trivial. However, it does appear that opaques are of slightly higher concentrations in cleavage zones and that the occurrence of carbonate and feldspar is basically restricted to the lithon (Figures 2-8a to 8d).

Based upon these data, it is reasonable to consider the rock as a quartz-mica assemblage with no great loss of accuracy.

2.4 Discussion

2.4.1 Petrography

There are features in the samples which are indicative of pressure solution. Specifically these are:

1) "trimming" and "elongation" of detrital quartz grains in cleavage zones

2) Sutured grain contacts between quartz grains

3) pressure shadows - quartz overgrowths and mica beards which are developed parallel to cleavage.

Also, the presence of predominantly insoluble micas and opaque minerals in cleavage zones is consistent with the idea of pressure dissolution of the more soluble quartz and calcite and their subsequent removal.

There may also have been intracrystalline deformation aiding the development of cleavage. Evidence for this includes:

1) undulatory (strained) extinction in the detrital quartz grains in both lithon and cleavage

2) subgrain development in quartz (recrystallization)

3) slightly deformed twin lamellae in both carbonate and feldspar.

The general conclusion that may be reached from the petrography of these sediments is that re-arrangement of minerals has occurred to yield the spaced cleavage; the evidence implies pressure solution as the major mechanism for this re-arrangement.

2.4.2 Mineral Distributions

Mineral variations across cleavage and lithon are important in formulating an explanation of what occurs during cleavage development. The most significant effect is the sharp decrease in quartz in the cleavage zones. The petrographic evidence for pressure solution suggests that the quartz in the cleavage has been partially dissolved.

In a study of similar cleavage in metasediments from Clunes, Australia, Stephens et al. (1978) concluded that the loss of silica from the mica-rich layers was due to preferential migration of fluid along those layers, the fluid dissolving and transporting material out of the system. This assumes the system is open; quartz, carbonate and feldspars may be partially or completely removed. As this removal continues, residual micas would concentrate along the channels forming cleavage zones.

It is impossible to know exactly how far the silica is transported in the system. It may be argued that some of the recrystallized quartz seen in the lithons represents a local end stage for the silica migration, but there is not a high enough percentage of such recrystallized/precipitated quartz in the lithon to account for the total loss from the cleavage.

There is a possibility that some of the mica in cleavage zones is new. In a study of pressure solution cleavage in sedimentary rocks, Beach (1979) concludes that the spaced cleavage zones are made up largely of newly crystallized mica flakes which accumulate as they form in cleavage zones. If this was the case in these samples, strong mica orientations would be expected in the cleavage zones, presumably different from the original mica orientations in the lithons. As will be seen in the next chapter of this thesis, this does not appear to be the case for the Goldenville rocks. In these rocks, cleavage zones appear to be primarily zones of residual mica concentration, with minor chemical adjustments.

CHAPTER 3

3.1 Mica Orientations

During point counting for modal analysis, the orientation of basal cleavage traces of micas was measured on a flat stage. Ideally, orientation data should be acquired using a universal stage, but in the absence of such a stage, measurements in the two perpendicular sections per sample were considered adequate. Results are displayed as frequency histograms (Figures 3-1, 3-2, 3-3, 3-4). For all histograms the percent mica is plotted for 5° angle intervals. The solid line represents cleavage data and the dotted line represents lithon data. Results of statistical analysis are listed separately.

These histograms show that in all cases:

1) the cleavages spread over the entire angular range, $0 \pm 90°$

2) the mean orientation coincides or nearly so with the cleavage zone orientation which is taken as zero

3) the majority of the orientations lie within $\pm 20°$ of the cleavage zone reference zero

4) the standard deviations of the orientation distributions are relatively small, and not greatly different for lithons and cleavage zones

5) bc sections show a more powerfully constrained distribution than do ac sections.

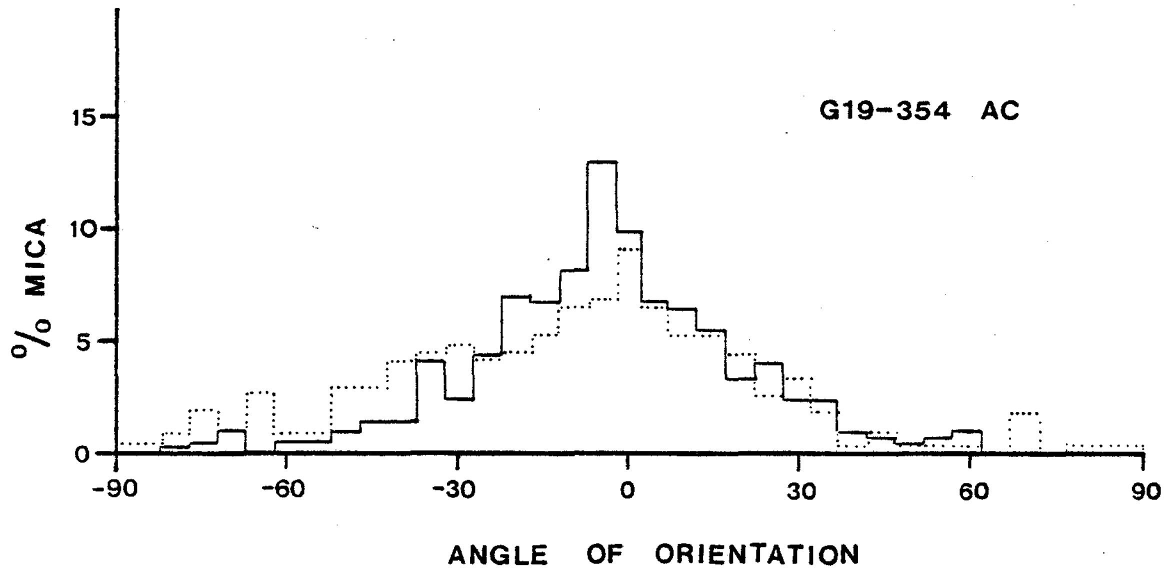
G19-354 AC

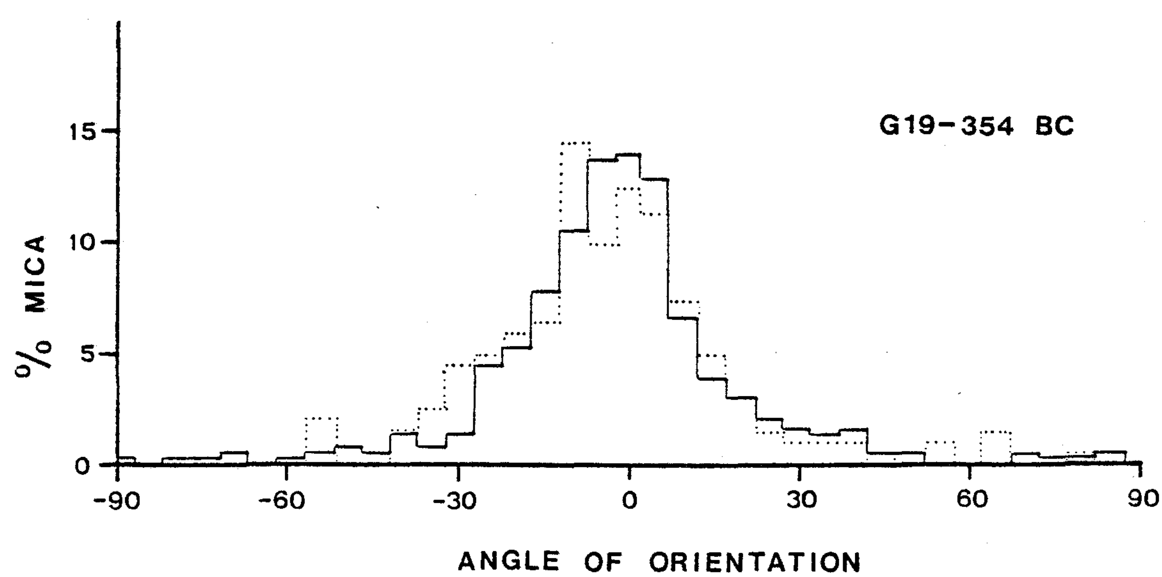
	CLEAVAGE	LITHON
Sample Size	355	263
Mean Orientation	-3°	-9°
Standard Deviation	13	17

FIGURE 3-1

G19-354 BC

	CLEAVAGE	LITHON
Sample Size	357	202
Mean Orientation	-2°	-3°
Standard Deviation	11	11


G19-354 AC
% MICA
0
5
10
15
-90
-60
-30
0
30
60
90
ANGLE OF ORIENTATION


G19-354 BC
% MICA
0
5
10
15
-90
-60
-30
0
30
60
90
ANGLE OF ORIENTATION

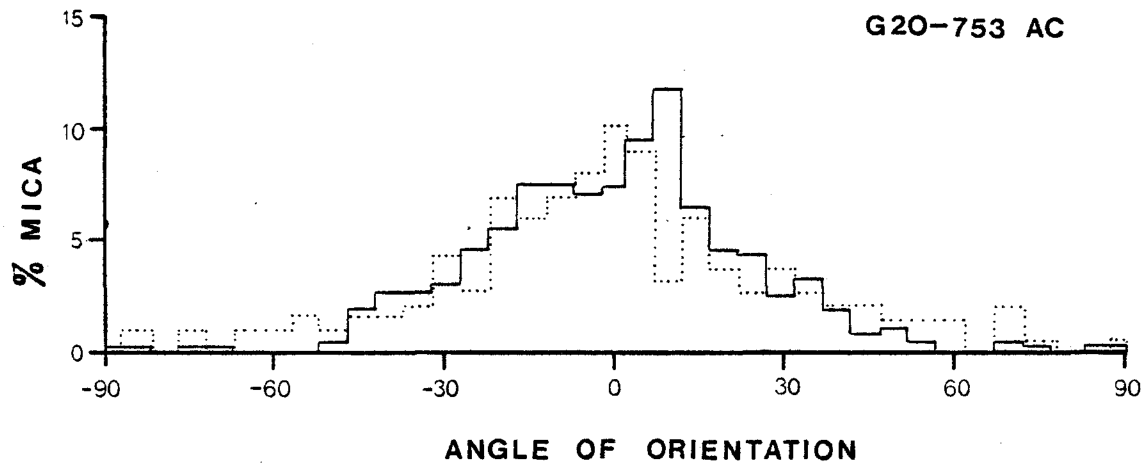
G20-753 AC

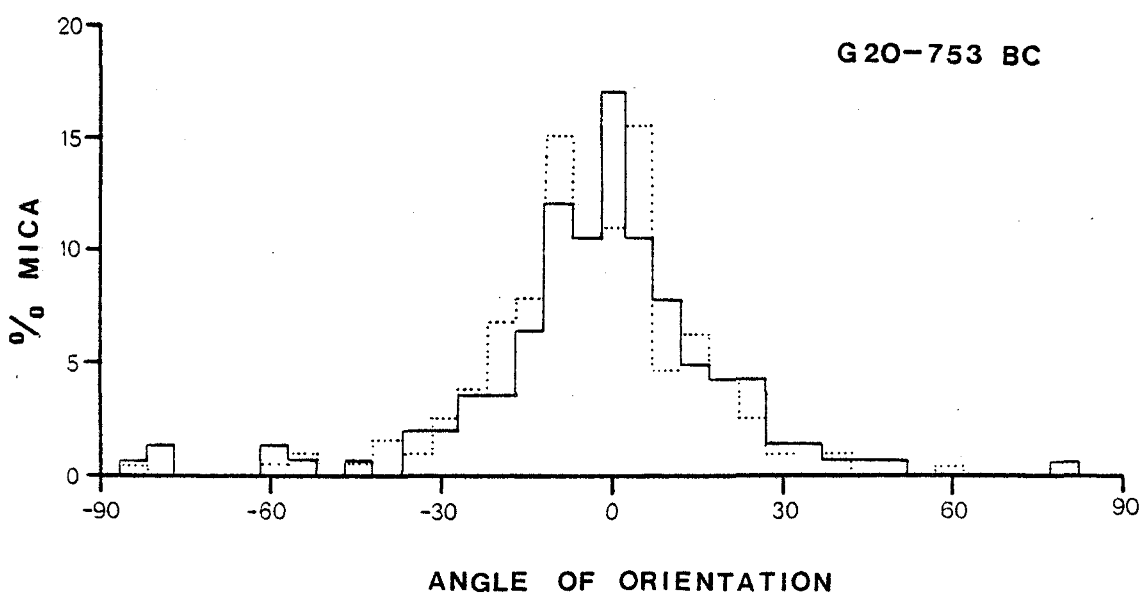
	CLEAVAGE	LITHON
Sample Size	367	188
Mean Orientation	0°	0°
Standard Deviation	10	17

FIGURE 3-2

G20-753 BC

	CLEAVAGE	LITHON
Sample Size	141	192
Mean Orientation	-2°	-3°
Standard Deviation	11	9


G20-753 AC
% MICA
15
10
5
0
-90
-60
-30
0
30
60
90
ANGLE OF ORIENTATION


G20-753 BC
% MICA
20
15
10
5
0
-90
-60
-30
0
30
60
90
ANGLE OF ORIENTATION

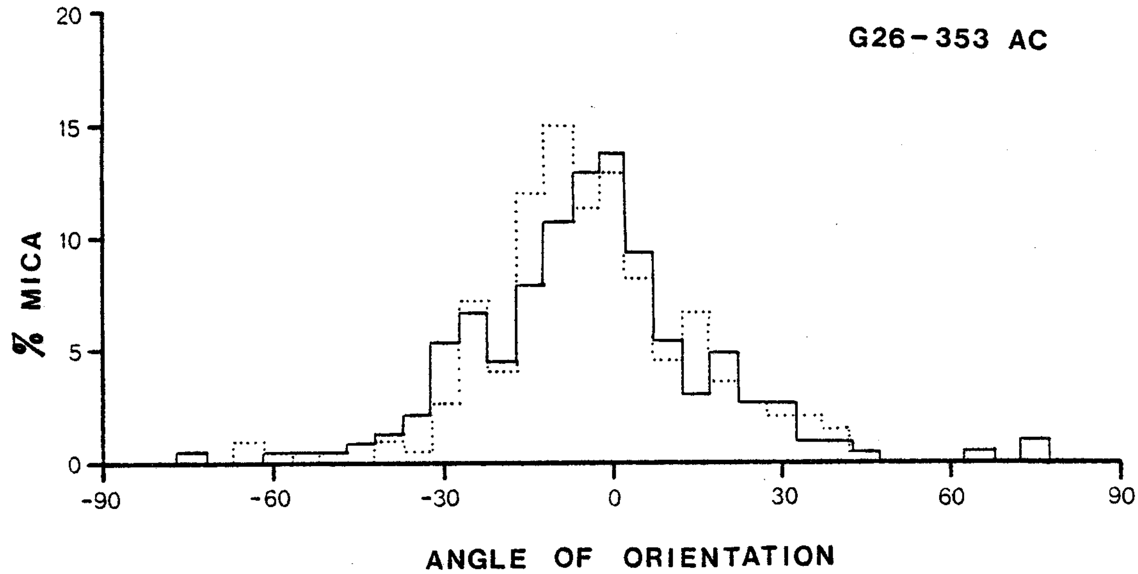
G26-353 AC

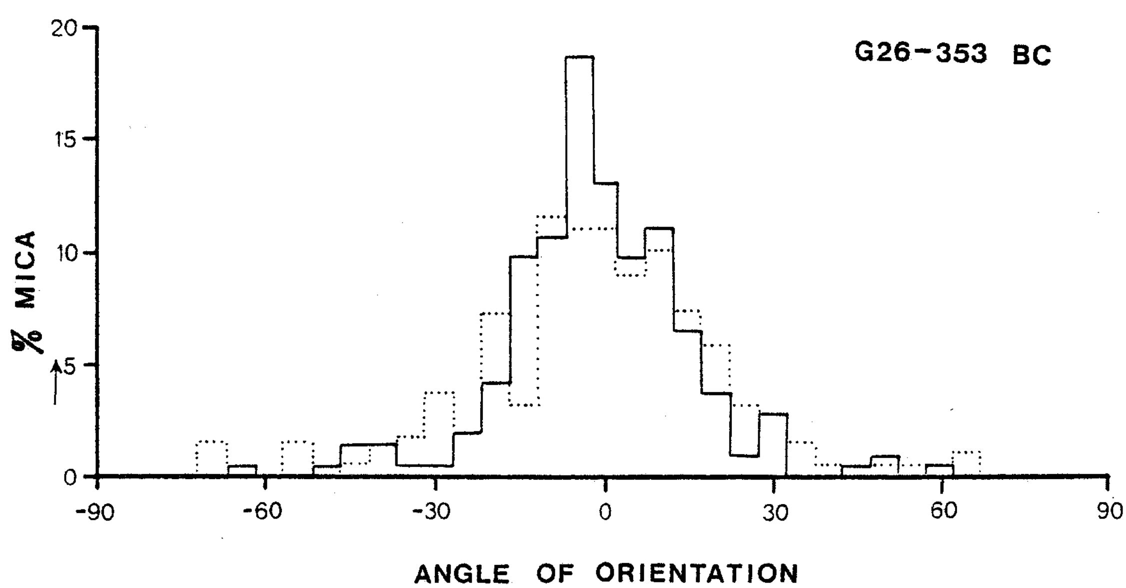
	CLEAVAGE	LITHON
Sample Size	214	189
Mean Orientation	-1°	-1°
Standard Deviation	8	11

FIGURE 3-3

G26-353 BC

	CLEAVAGE	LITHON
Sample Size	224	194
Mean Orientation	-4°	-3°
Standard Deviation	10	9


G26-353 AC
% MICA
20
15
10
5
0
-90
-60
-30
0
30
60
90
ANGLE OF ORIENTATION


G26-353 BC
% MICA
20
15
10
5
0
-90
-60
-30
0
30
60
90
ANGLE OF ORIENTATION

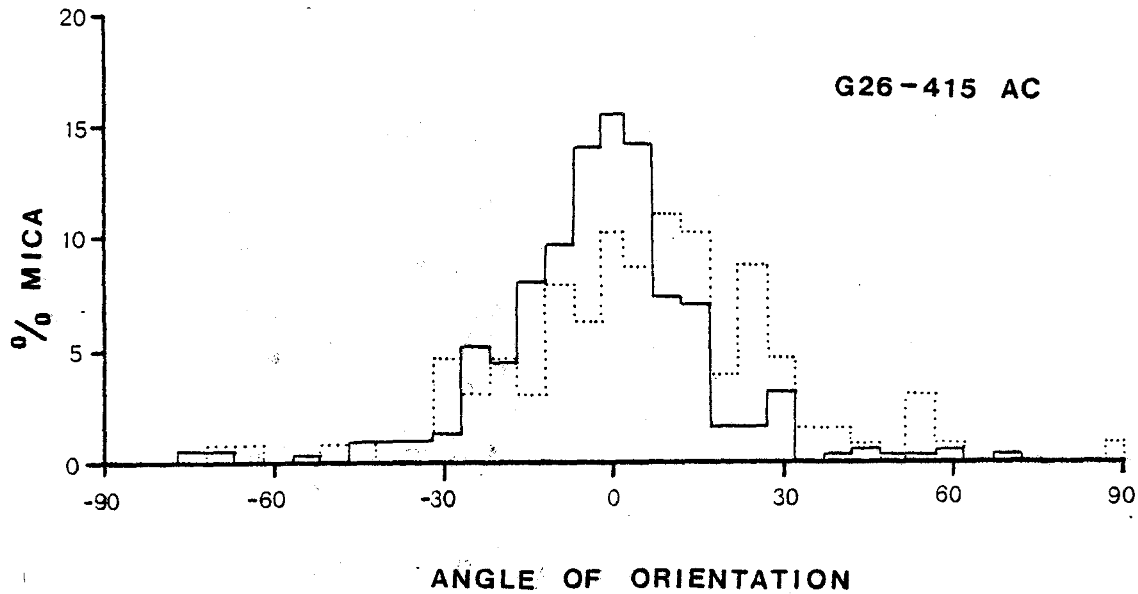
G26-415 AC

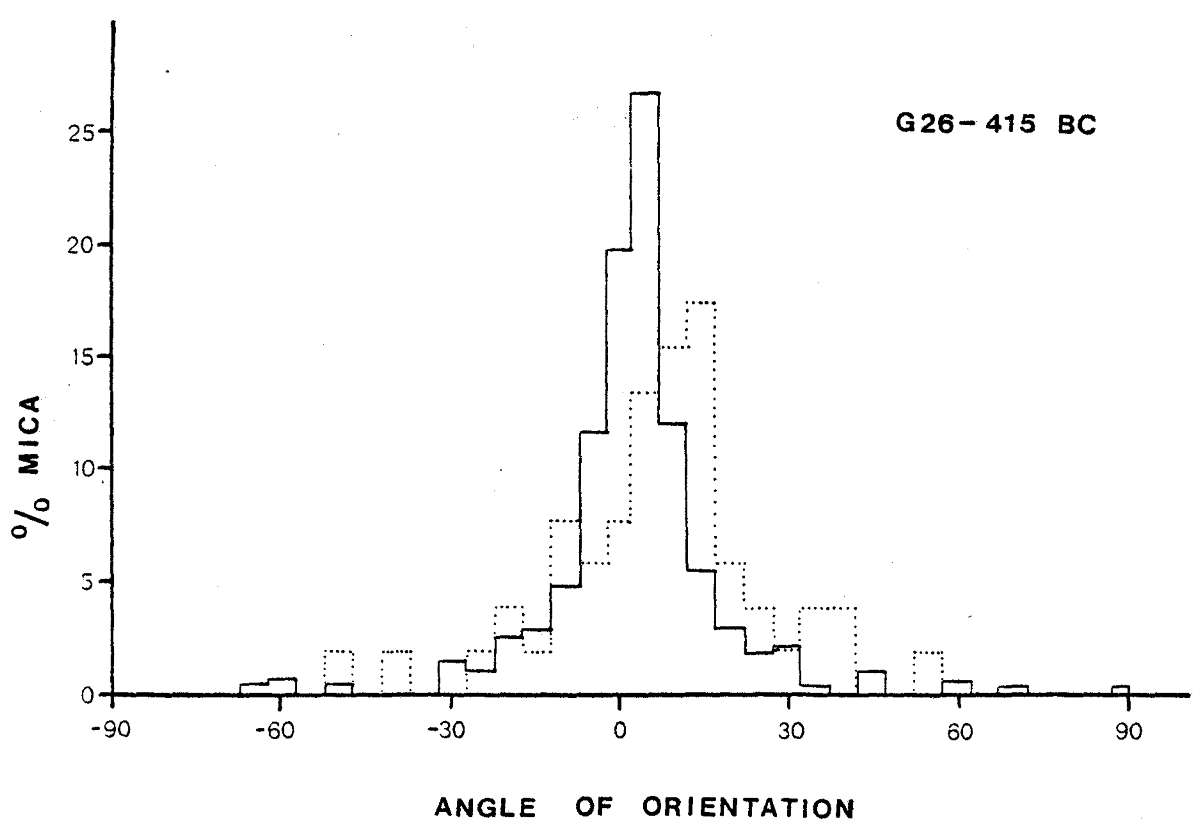
	CLEAVAGE	LITHON
Sample Size	310	127
Mean Orientation	-2°	5°
Standard Deviation	9	13

FIGURE 3-4

G26-415 BC

	CLEAVAGE	LITHON
Sample Size	273	52
Mean Orientation	3°	7°
Standard Deviation	9	9


G26-415 AC
% MICA
20
15
10
5
0
-90
-60
-30
0
30
60
90
ANGLE OF ORIENTATION


G26-415 BC
% MICA
25
20
15
10
5
0
-90
-60
-30
0
30
60
90
ANGLE OF ORIENTATION

In general, the better developed cleavage zones also show the smaller standard deviations.

The remarkable aspect of these data is that the angular distributions in lithons and cleavage zones for each sample are so similar. The preconception was that compared with the pattern in the lithons, micas in cleavage zones were much more constrained in their orientations. This is clearly not the case, as is demonstrated by these measurements. The results support the argument against new mica crystallization formed during cleavage development and so the assumption of residual mica accumulation in cleavage zones stands.

The results suggest that whatever the orientation mechanism, as it affects micas, it is not much more powerful in cleavage zones than it is in lithons of the same rock. However, the effectiveness of the process does appear relatable to the effectiveness of pressure solution generally, because greater solution corresponds to a more constrained distribution (compare weakly developed cleavage in G20-753 AC [Figure 2-6e] and strongly developed cleavage in G26-415 BC [Figure 2-6b]).

3.2 Shortening

In order to estimate the amount of shortening which has occurred during cleavage development in the Goldenville greywackes, it has been assumed that:

1) pressure solution was the dominant mechanism acting to preferentially dissolve quartz from cleavage zones

2) fluid has removed quartz (± carbonate, feldspar) from the system

3) cleavage zones are composed of concentrated residual micas.

These statements are very reasonable for these samples.

A simple calculation for amount of shortening is based on a comparison of the amount of mica in cleavage zones with the amount of mica in lithons. If it is assumed that the lithon represents relatively unaffected rock (in that it escaped major solution effects), then the amount of mica present in lithon areas may be taken to represent the initial mica concentration in the cleavage zones. As shortening occurs, the mica concentration increases in evolving cleavage zones and the final amount of mica present may be expressed as a function of "how many lithons" it would take to provide that total amount of mica now present in the cleavage zone.

A simple mathematical expression for this model is:

$$\left[\frac{\%\text{ mica in lithon}}{\%\text{ mica in cleavage}} - 1\right] \times 100\% = \%\text{ loss (shortening)}$$

Estimates of shortening were made for each sample using average percentages of mica for both cleavage and lithon zones; results are presented in Table 3-1. Sample G26-415 has a very well developed, wide cleavage zone and consequently shows very high shortening values. The low value for Sample G19-354 BC corresponds to poor development of cleavage planes in that section. The average values are between 50% and 60% shortening.

The rocks under consideration are essentially two component systems, quartz and mica. In this case, shortening values may be converted to an equivalent one-dimensional volume loss of quartz from the system. Figures 3-5a to 3-5d illustrate the movement of quartz in these samples.

Pryer (1984) also considered the loss of quartz to equal the loss of volume from the cleavage. Based on measurements of strain due to pressure solution, similar results were obtained; the values of silica loss were 40% or greater to the system as a whole, ranging up to 70% volume loss in individual cleavage zones.

These values also agree with the volume losses determined by chemical analyses (Fueten et al., 1983).

TABLE 3-1

Calculated shortening values for each Sample and equivalent volume loss (average for each Sample).

SAMPLE	SHORTENING	VOLUME LOSS
G19-354 AC	62.3%	54%
G19-354 BC	43.5%	
G20-753 AC	50.3%	51%
G20-753 BC	52.2%	
G26-353 AC	55.4%	59%
G26-353 BC	62.2%	
G26-415 AC	84.1%	84%
G26-415 BC	83.1%	

Figures 3-5a to 3-5d

Variations in mica/quartz ratios across samples.

Vertical dashed lines represent cleavage zones.

Note increases in cleavage zones.

a) G19-354 AC

G19-354 BC

b) G20-753 AC

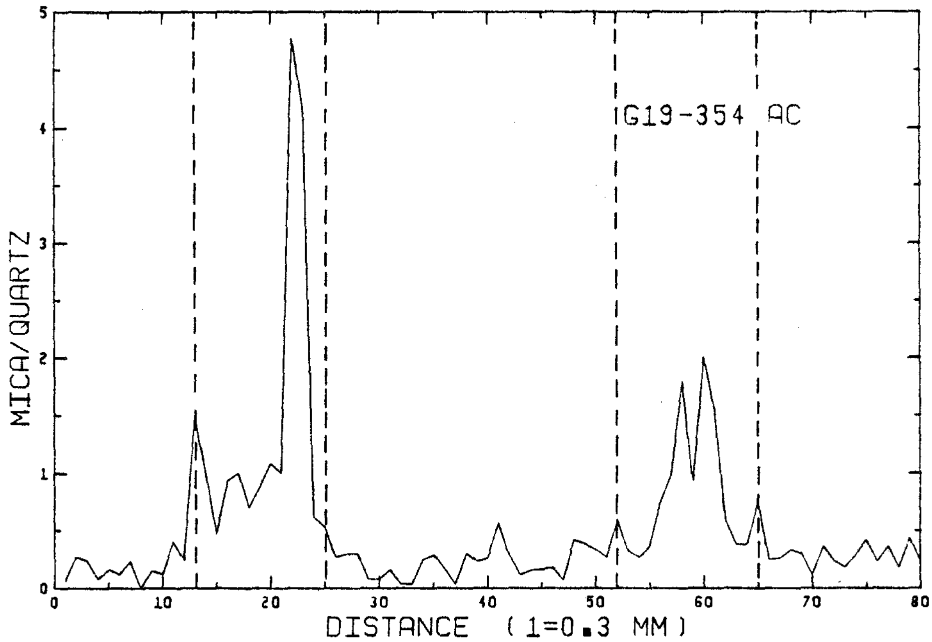
G20-753 BC

c) G26-353 AC

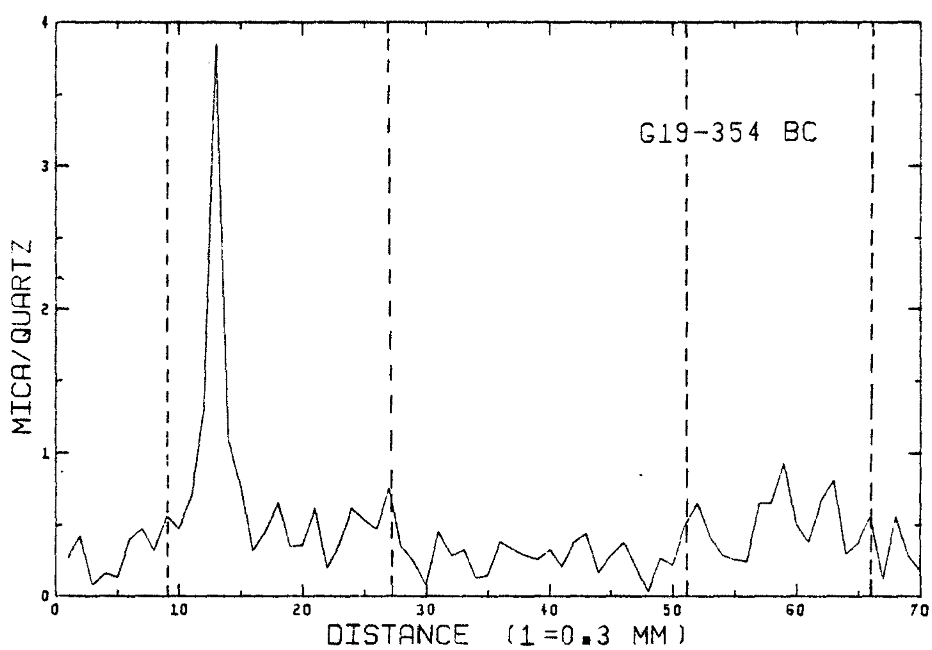
G26-353 BC

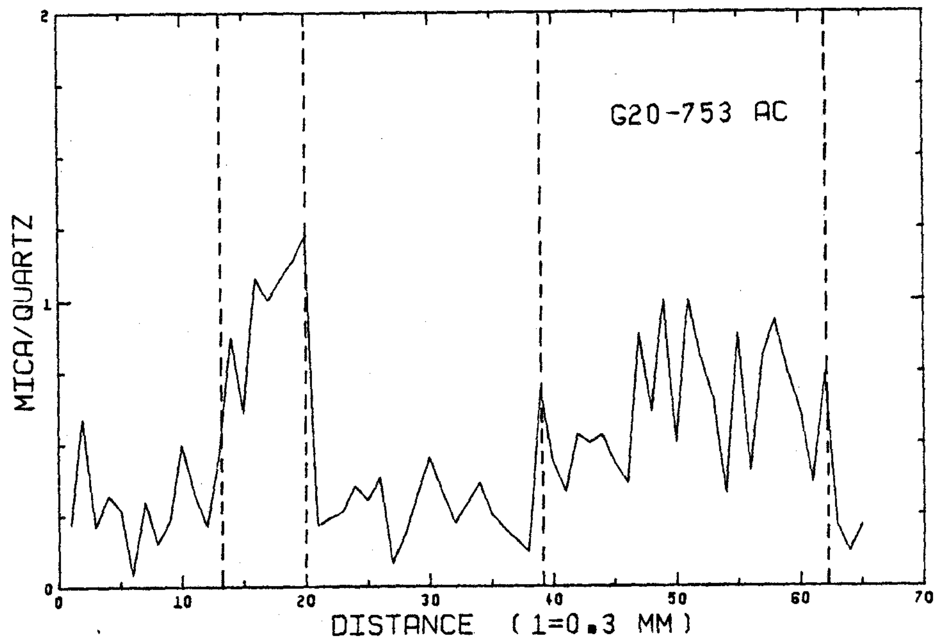
d) G26-415 AC

G26-415 BC

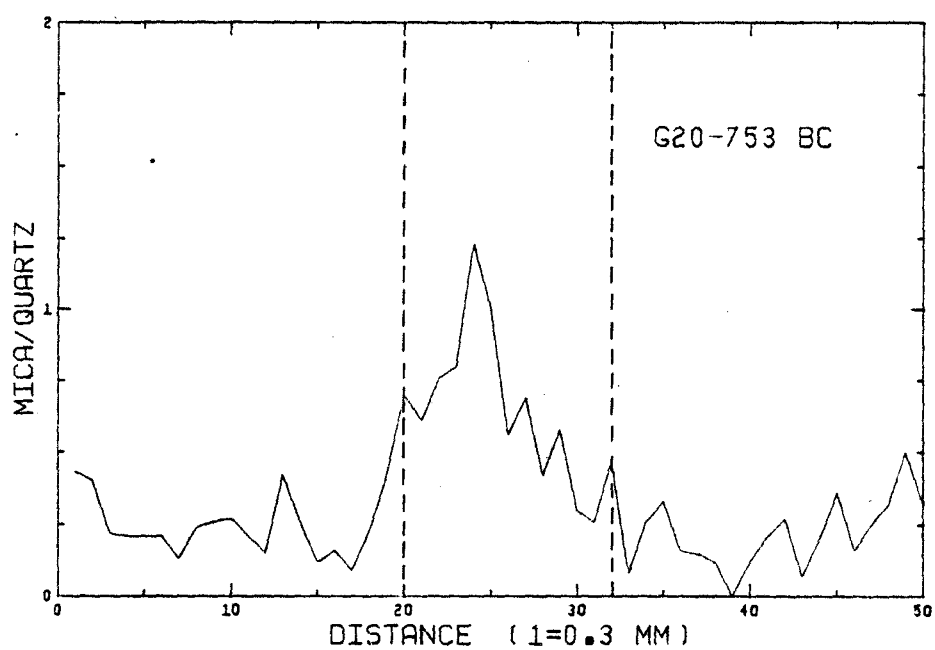

G19-354 AC
MICA/QUARTZ
DISTANCE (1=0.3 MM)
0
1
2
3
4
5
0
10
20
30
40
50
60
70
80

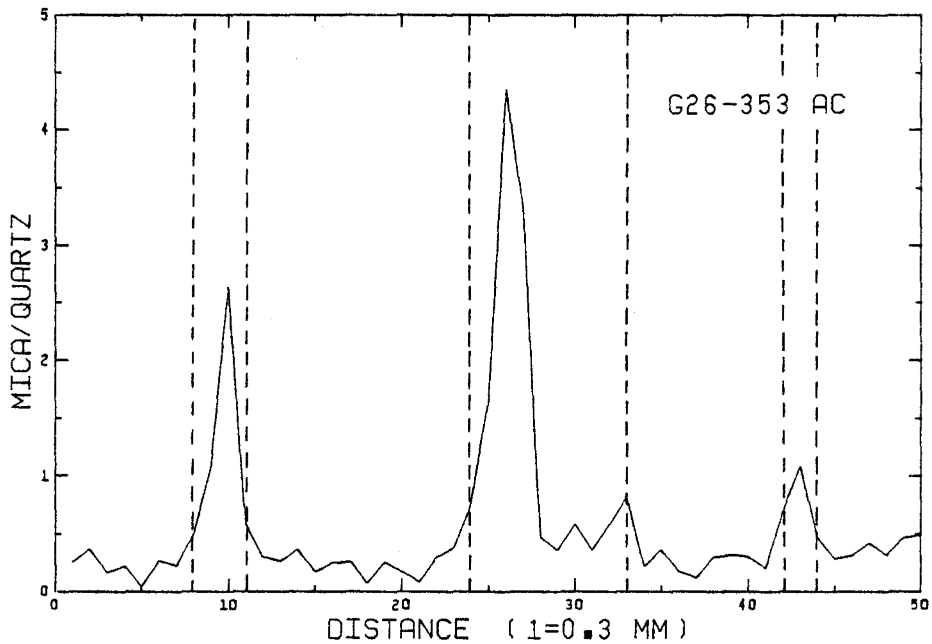
(a)


G19-354 BC
MICA/QUARTZ
DISTANCE (1=0.3 MM)
0
1
2
3
4
0
10
20
30
40
50
60
70

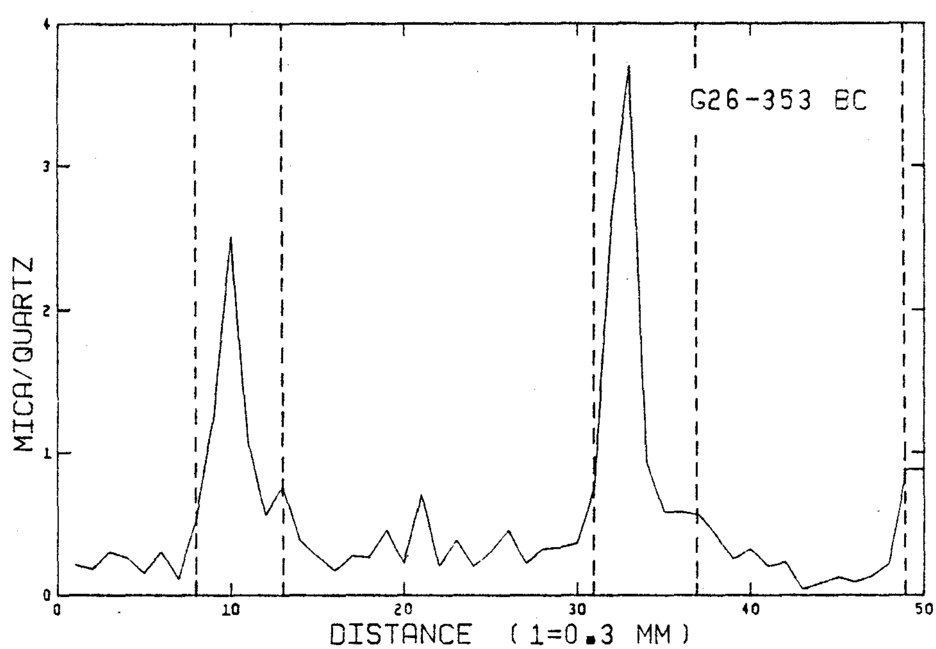

G20-753 AC
MICA/QUARTZ
DISTANCE (1=0.3 MM)
0
1
2
10
20
30
40
50
60
70

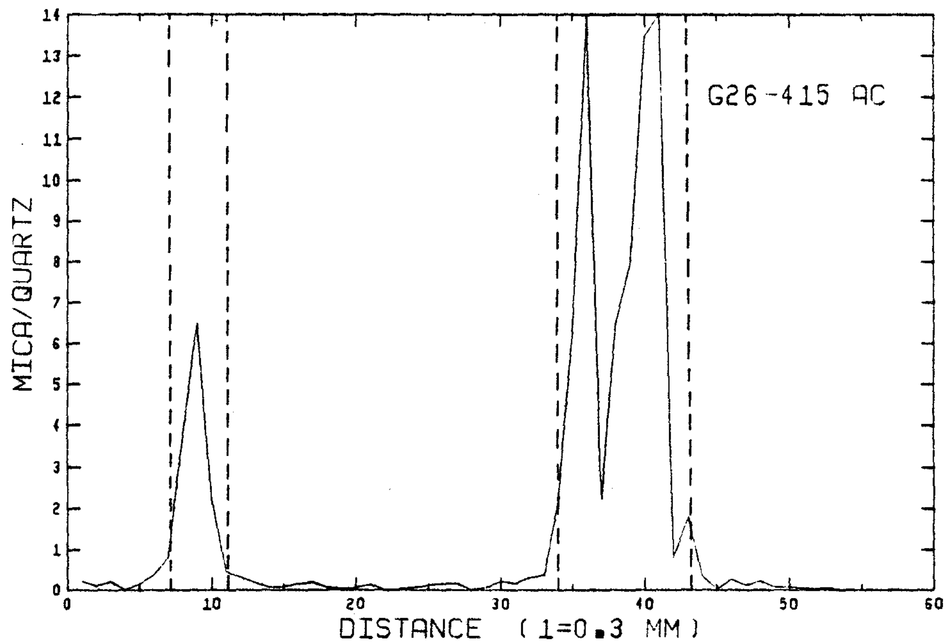
(b)


G20-753 BC
MICA/QUARTZ
DISTANCE (1=0.3 MM)
0
1
2
10
20
30
40
50

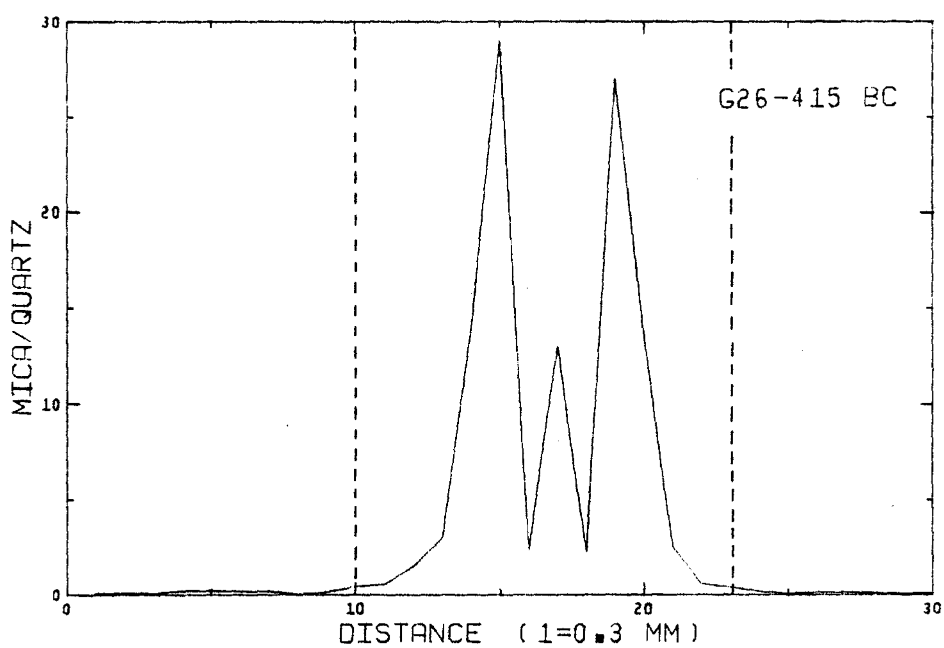

G26-353 AC
MICA/QUARTZ
DISTANCE (1=0.3 MM)
0
1
2
3
4
5
10
20
30
40
50

(c)


G26-353 BC
MICA/QUARTZ
DISTANCE (1=0.3 MM)
0
1
2
3
4
10
20
30
40
50


G26-415 AC
MICA/QUARTZ
DISTANCE (1=0.3 MM)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
0
10
20
30
40
50
60

(d)


G26-415 BC
MICA/QUARTZ
DISTANCE (1=0.3 MM)
0
10
20
30
0
10
20
30

CHAPTER 4

4.1 Summary

The Goldenville greywackes can be thought of as essentially two component systems, 70% quartz and 30% phyllosilicates. The rocks possess an obvious spaced cleavage, clearly defined by zones of high concentrations of micas. Petrographic evidence suggests that the dominant mechanism affecting these rocks has been pressure solution. Dissolution of quartz has occurred and a fluid transport mechanism is required to remove the quartz from the system. This movement of silica results in zones of high mica to quartz ratios along the fluid channels, producing the spaced cleavage zones observed. The degree of cleavage development depends upon the local degree of pressure solution.

A large amount of shortening occurs during cleavage development due to the volume loss of quartz. Comparison of the shortening values determined here for the Goldenville anticline with those determined by other authors leads to the conclusion that shortening values of 50% to 60% are not unreasonable.

References

Beach, A. (1979). Pressure solution as a metamorphic process in deformed terrigenous sedimentary rocks. Lithos, 12, 51-58.

Boer, R.B. de (1977). On the thermodynamics of pressure solution - interaction between chemical and mechanical forces. Geochem. Cosmochim. Acta, 41, 249-256.

Durney, D.W. (1976). Pressure solution and crystallization deformation. Phil. Trans. R. Soc., A283, 229-240.

Fueten, F., Clifford, P.M., Pryer, L.L., Thompson, M.J., and Crocket, J.H., (in press). Distribution and localization of gold in Meguma Group rocks, Nova Scotia. Part III - Shortening and cleavage production and widespread mass removal of SiO2.

Fyson, W.K. (1967). Gravity sliding and cross folding in Carboniferous rocks, Nova Scotia. Am. J. Sci., 265, 1-11.

Graves, M.C. (1976). The formation of gold-bearing quartz veins in Nova Scotia. M. Sc. Thesis, Dalhousie University.

Harris, A.L. et al. (1976). The evolution of the Tay nappe. Scott.J. Geol., 12, 103-113.

Henderson, J.R. (1983). Analysis of structure as a factor controlling gold mineralization in Nova Scotia. Geol. Surv. Can. Paper 83-1B, 13-21.

Poole, W.H. (1971). Graptolites, copper and K-Ar in the Goldenville Formation, Nova Scotia. Geol. Surv. Can. Paper 71-1, Part A, 9-11.

Pryer, L.L. (1984). Unpublished B.Sc. thesis. Strain Estimates in the Metagreywackes of the Goldenville Formation, Meguma Group, Nova Scotia. McMaster University

Schenk, P.E. (1970). Regional variation of the Flysch-like Meguma Group (Lower Paleozoic) of Nova Scotia, compared to Recent Sedimentation off the Scotian Shelf. Geol. Assoc. Can., Spec. Paper 7, 127-153.

Schenk, P.E. (1971). Southeastern Atlantic Canada, northwestern Africa and continental drift. Can. J. Earth Sci., 8, 1218-1251.

Sorby, H.C. (1863). Uber Kalkstein - Geschiebe mit Eindrucken. Jahrbuch F. Mineralogie, 801-807.

Stephens, M.B., et al. (1978). Structural and chemical aspects of metamorphic layering development in metasediments from Clunes, Australia. Am. Jour. Sci., 278.

Taylor, F.C. and Schiller, E.A. (1966). Metamorphism of the Meguma Group of Nova Scotia. Can. J. Earth Sci., 3, 959-974.

Watson, G.S. (1966). The statistics of orientation data. Jour. Geol., 14, 786 - 796.

Williams, P.F. (1972). Development of metamorphic layering and cleavage in low grade metamorphic rocks at Bermagui, Australia. Am. J. Sci., 272, 1-47.